CONFIDENTIAL

COAL-OIL SLURRY SEPARATION BY CONTINUOUS SCREEN-BOWL CENTRIFUGE

by

Staff, Engineering Division, Saskatchewan Research Council

July, 1982

SRC Publication No. E-725-7-C-82

SASKATCHEWAN RESEARCH COUNCIL

DECLASSIFIED
DATE June 12/90
AUTHORIZED BY M. Dewhurst

COAL-OIL SLURRY SEPARATION BY CONTINUOUS SCREEN-BOWL CENTRIFUGE

91-04794/

FINAL REPORT

by

Staff, Engineering Division, Saskatchewan Research Council

Work on this project was conducted under the auspices of the Canada Centre for Mineral and Energy Technology, Energy Mines and Resources Canada

DSS FILE NUMBER: 17SQ. 23440-0-9073

DSS CONTRACT SERIAL NUMBER: OSQ81-00001

CANMET PROJECT NUMBER:

CANMET SCIENTIFIC AUTHORITY: M. SKUBNIK

JULY, 1982

ENGINEERING DIVISION,
SASKATCHEWAN RESEARCH COUNCIL

80 pp

MICROMEDIA

SUMMARY

Slurries of ground metallurgical and thermal coals in synthetic crude oil were subjected to attrition tests simulating pipeling transportation: The two moist thermal coals in 45 wt% slurry suffered no surely observable degradation. The dried metallurgical coal in 50% by wt slurry, however, did undergo some degradation in that its -325 mesh fines increased from about 12% to about 17%.

These slurries were then centrifuged in a Bird continuous screen-bowl centrifuge. Feed rates varied from about 0.1 L/min to about 10 L/min. Gravitational accelerations were 775, 1000, and 1500 G, with no apparent effects of change in G being seen.

Three products were obtained from the centrifuge per test: a solid, a liquid effluent and a middling or screen product. Normally the solid contained 90 - 95% coal, the liquid 0.5 - 3% coal, and the screen product (30) - 40 - (50)% coal.

The liquids lowest in coal were made from that thermal coal which was lowest (about 3%) in subsieve fines. Change of feed rate from 0.5 L/min on up to 10 L/min normally had little effect on coal content of the products, except that high feed rates tended to make for more coal in the liquid product. The primary effect of change of feed rate was to change the weight proportions of the products; usually the solid and liquid production rates were subequal and the proportion of screen product lessened as feed rate grew greater. Operation of the centrifuge was smoothest at high feed rates (7.5 or 10 L/min) and screen plugging was less of a problem.

Particle size determinations were done on the coal fractions of the

products from the centrifugations. The coal of the solid products was predominantly larger than 0.305 mm (the diameter of the holes in the screen) and that of the screen product ran on down from this figure. The coal in the liquid product was 50 - 90% below 325 mesh. Change of feed rate had no consistent effect upon the particle size distribution of the coal in the products.

Evidence was obtained that the size distribution of the minus 325 fines is continuous down to 1μ and probably smaller.

The assumption that the water content of the coal is unchanged by slurrying in oil was checked for a few samples by absorption with P_2O_5 and found to hold good.

Recycle of screen product gave unsatisfactory results.

There was some evidence that degradation of the metallurgical coal continued in the centrifuge.

Quantities of liquid and solid products were produced under selected favourable conditions for product evaluation. Analyses of the liquid product as done by Imperial Oil are appended.

TABLE OF CONTENTS

		PAGE
	Summary	
1.	Introduction	1
	1.1 Purpose	1
	1.2 Summary of Work To Be Done	1
2.	Apparatus & Materials	6
	2.1 For Attrition Runs	6
	2.2 For The Centrifuging Tests	6
	2.3 Coals and Oil Used	7
3.	Procedure	9
	3.1 Slurry Making	9
	3.2 Attrition Runs	9
	3.3 Centrifuging Runs	10
4.	Methods of Analysis	11
	4.1 Sieving	11
	4.2 Subsieve Particle Size Distribution by Sedigraph (R)	12
	4.3 Moisture Contents of Coals and Centrifuge Products	13
5.	Results	14
	5.1 Wabamun Coal, Tasks 2 & 3	14
	5.2 Vesta Coal, Tasks 2 & 3	14
	5.3 McIntyre Coal, Tasks 2 & 3	16
	5.4 Task 4; Centrifugings of Test Quantities of Products from All Three Coal Slurries	17
	5.5 Results from the Sedigraph; Existence of Subsieve Fines	19
	5.6 Water Content of Oiled Coals by P_2O_5 Absorption	20

TABLE OF CONTENTS CONTINUED

PAGE

6. Discussion of Specific Result Tables 20
   6.1 Wabamun, Tasks 2 & 3. 20
   6.2 Vesta, Tasks 2 & 3. 23
   6.3 McIntyre, Tasks 2 & 3 24
   6.4 Task 4 Centrifugings. 26
   6.5 Sedigraph Results 27
   6.6 Moisture Content of Oiled Coals 28
   6.7 Comments on Overall Results 28
7. Conclusions and Recommendations 30
   7.1 Conclusions 30
   7.2 Recommendations 30
8. Reference. 32
9. Result Tables. 33
   Appendix A: The Contract. 59
   Appendix B: Results from Imperial Oil 65
   Appendix C: Data on Duro pump 71

FIGURES

PAGE

1. Pump Attrition Loop. 3
2. Centrifuge Test Setup. 4
3. Bird Centrifuge. 5

TABLES

PAGE

1. Birtley's P.S.D.'s by Wet Screening of Coals, in wt %. 33
2. Water Contents and Densities of Coals Used 33
3. Particle Size Distributions of Feed, Wabamun expt. 34
4. Bird Centrifugings on Wabamun Coal Slurry, 45% Coal by wt. (nominal). 35
5. Distribution of Centrifuge Products From Wabamun Coal Slurries. 36
6. Particle Size Distributions of Wabamun Coal in Centrifuge Products: Solid Product 37
7. Particle Size Distributions of Wabamun Coal in Centrifuge Products: Middlings (Screen product). 38
8. Particle Size Distributions of Wabamun Coal in Centrifuge Products: Liquid Product. 39
9. Particle Size Distributions of Feed, Vesta Expt. 40
10. Bird Centrifugings on Vesta Coal Slurry, 45% Coal by wt. (nominal). 41
11. Distribution of Centrifuge Products From Separation of Vesta Coal, per minute 42
12. Particle Size Distributions of Vesta Coal In Centrifuge Products: Solid Product. 43
13. Particle Size Distributions of Vesta Coal in Centrifuge Products: Middlings (Screen Product) 44
14. Particle Size Distributions of Vesta Coal in Centrifuge Products: Liquid Product 45
15. Particle Size Distributions of Feed: McIntyre Expt.. 46
16. Bird Centrifugings on McIntyre Coal Slurry, 54% Coal By Wt. (Experimental value) 47
17. Distribution of Centrifuge Products From Separation Of McIntyre Coal, Per Minute 48
18. Particle Size Distributions of McIntyre Coal in Centrifuge Products: Solid Product 49

TABLES CONTINUED

PAGE

19. Particle Size Distributions of McIntyre Coal In Centrifuge Products: Middlings (Screen Product) 50

20. Particle Size Distributions of McIntyre Coal in Centrifuge Products: Liquid Product 51

21. Initial Solids Content and Particle Size Distributions, Task 4 Slurries 52

22. Task 4 Centrifugings on Coal Slurries. 53

23. Proportions of Products in Task 4 Centrifugings. 54

24. P.S.D. of Solids in Solid Products From Task 4 Centrifugings . 55

25. P.S.D. of Solids in Middlings From Task 4 Centrifugings. . . . 56

26. P.S.D. of Solids in Liquid Product From Task 4 Centrifugings . 57

27. Moisture Determination By Drying with P_2O_5 58

1 INTRODUCTION

1.1 PURPOSE

A contract from CANMET through DSS to the Engineering Division, Saskatchewan Research Council was let to study whether slurries of coal in crude oil would suffer significant degradation by pipelining to Eastern Canada, and how much separation of the pipelined slurry into its components can be achieved by continuous centrifugation. This was envisaged as a sequel to SRC report E76-3 (1).

1.2 SUMMARY OF WORK TO BE DONE

The contract in full is given as Appendix A, but its provisions may be summarized thus:

Task 1 was to prepare slurries in light crude oil of two thermal coals at 45% solids and of one metallurgical coal at 50% solids, and to circulate these in an apparatus for simulation of long distance slurry pipeline transportation.

Task 2 was to centrifuge these slurries in a Bird continuous screen-bowl centrifuge over a span of feed rates from 0.1 kg/min to 10 kg/min and using speeds such as to give multiples of gravitational acceleration, of 750, 1000, and 1500. (In practice feed rates were measured in L/min for convenience, which were numerically close to kg/min). Some tests with recycle of middlings were also required.

Task 3 was to analyze samples of the products from all these centrifuge runs for solids content and particle size distribution of such solids down to 0.3 μm. Moisture contents of the products were also requested.

Task 4 was, after consultation with the Scientific Authority, to carry out larger scale centrifugings of the coal slurries, large enough

to provide 20 to 50 L samples of liquid product and about as much solid product. The liquid was to be sent to an oil company laboratory for evaluation as a crude oil; the solids were to be sent elsewhere as directed. CANMET was to receive equal quantities of the liquid products as the oil company.

Task 5 was to analyze samples from the production runs of Task 4 as Task 3 had analyzed the samples from Task 2.

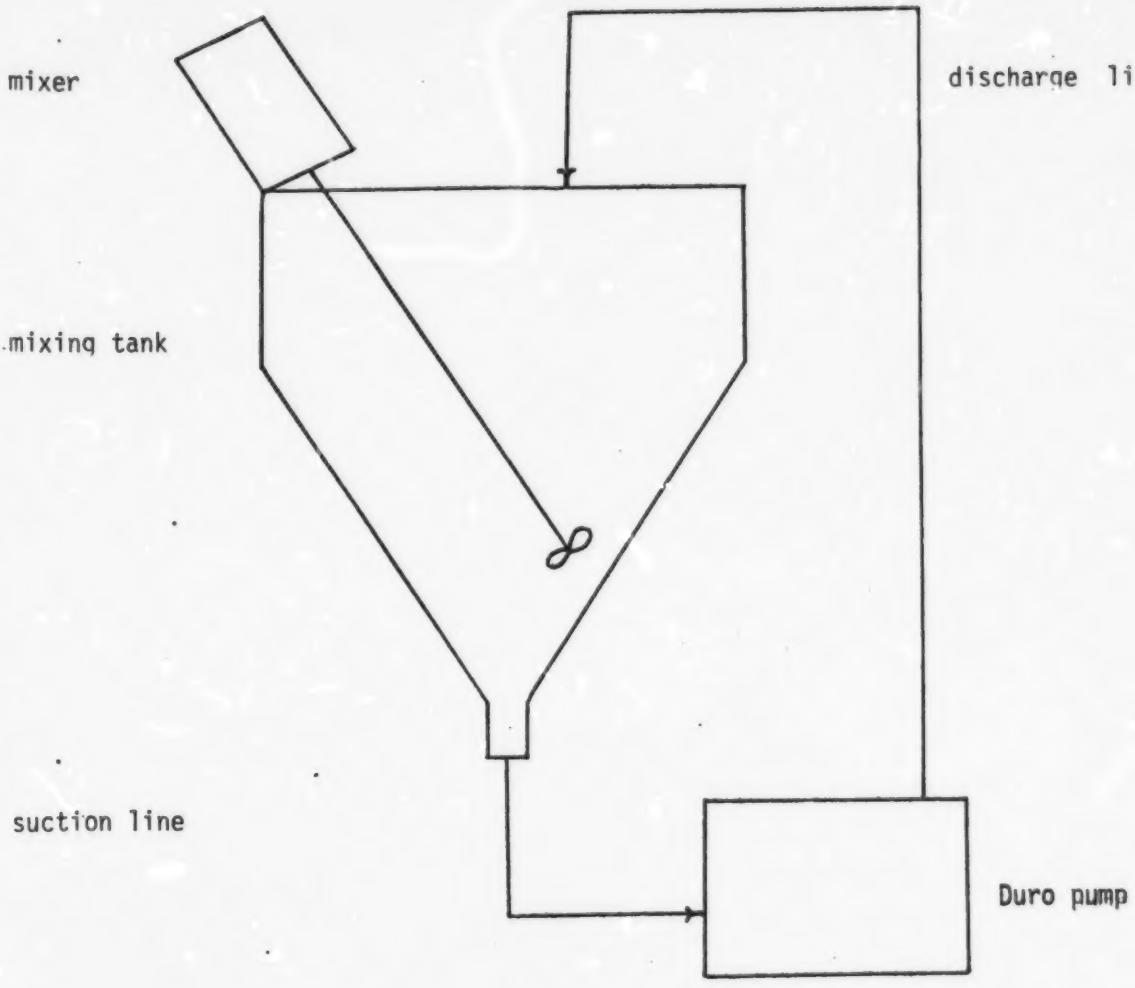

Fig. 1 PUMP ATTRITION LOOP

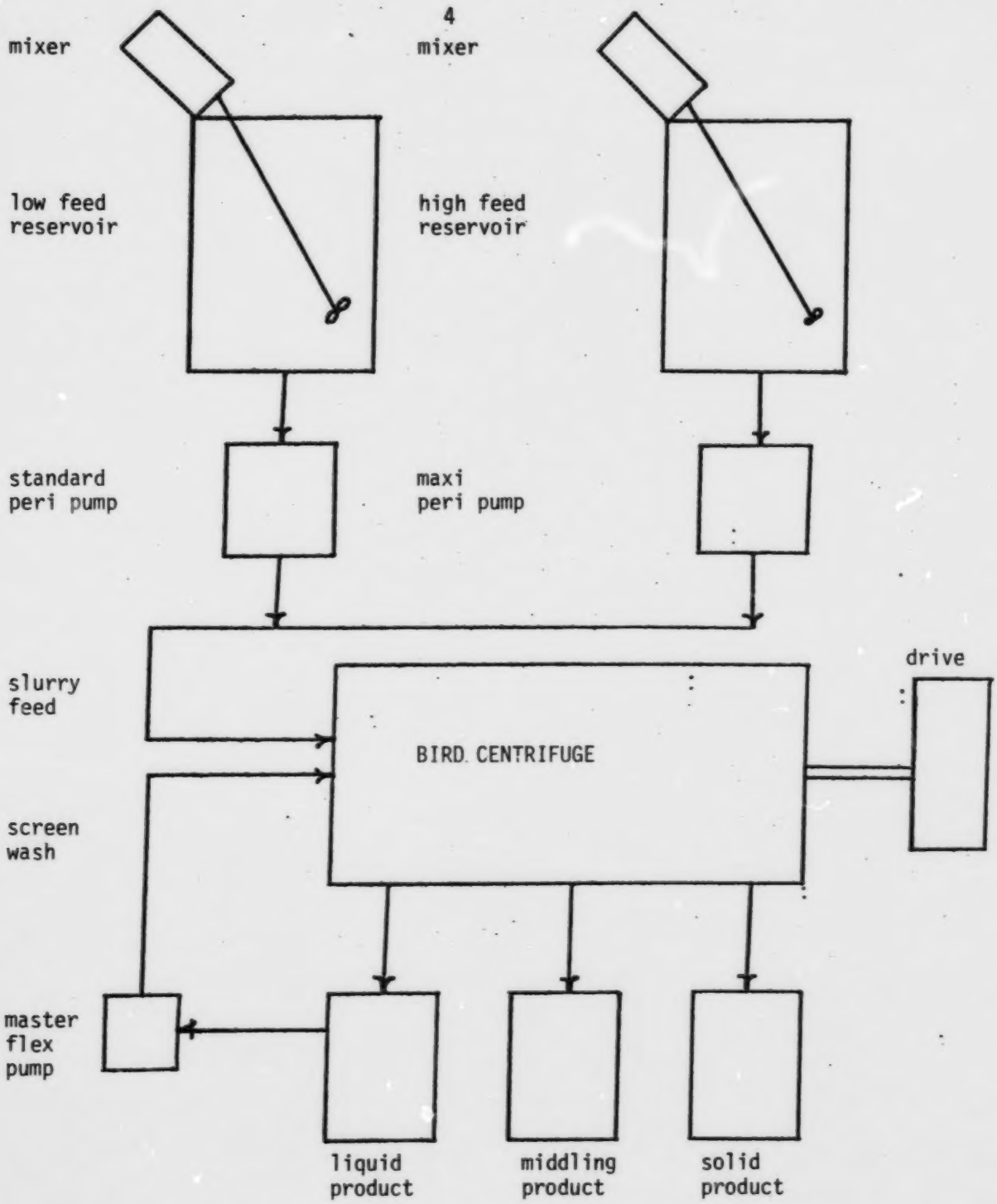

Fig. 2 CENTRIFUGE TEST SETUP

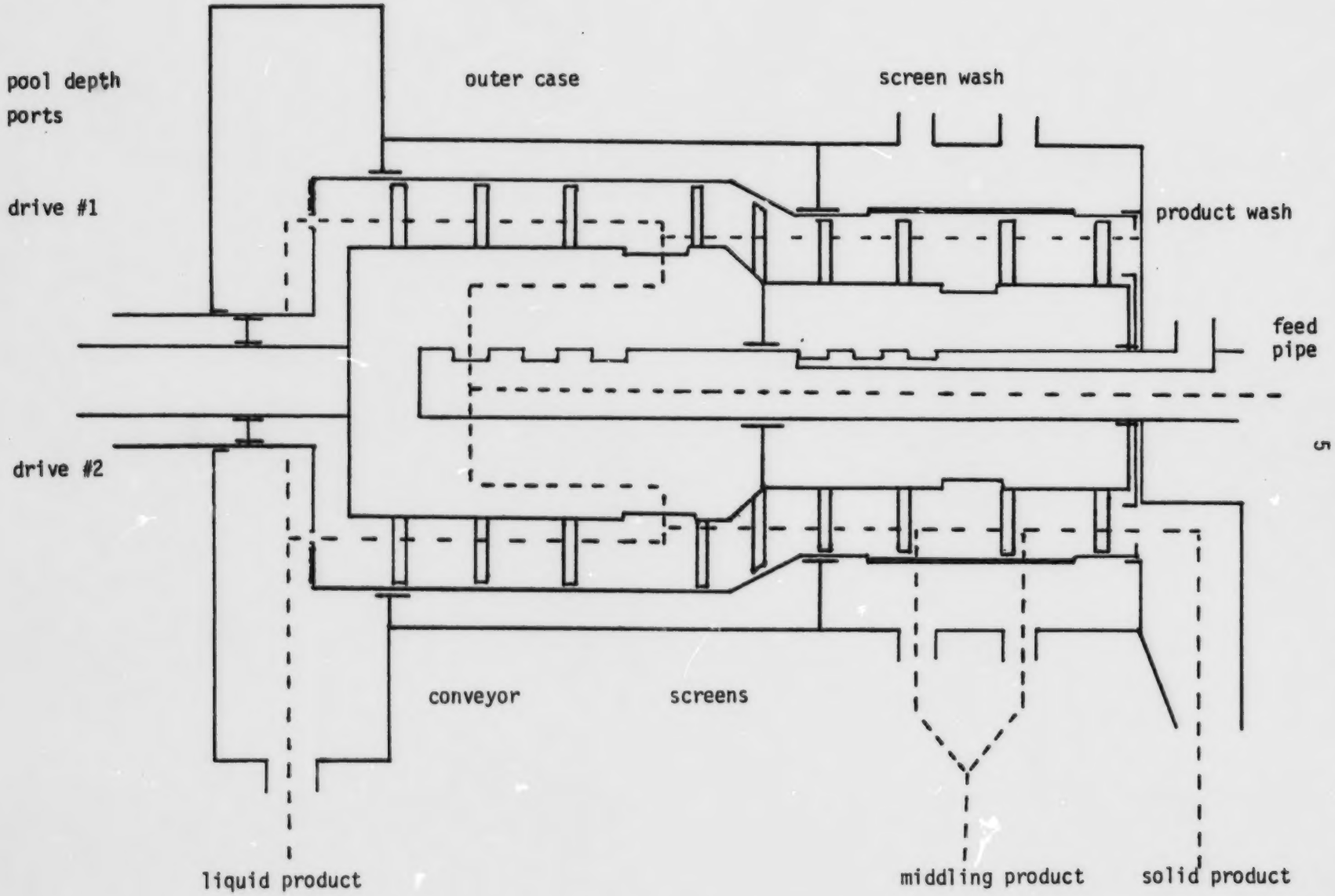

Fig. 3 BIRD CENTRIFUGE SCHEMATICALLY

(OR DIAGRAMMTICALLY)

2 APPARATUS AND MATERIALS

2.1 FOR ATTRITION RUNS

A flow diagram of the pump attrition loop is given in Figure 1. A conical-bottomed tank is shown containing the slurry, which is kept mixed with a 1/3 H. P. Lightnin' mixer operating at about 400 r.p.m.

The cone-bottomed tank feeds a pump which recirculates the fluid to the tank by a hose.

As positive displacement pumps are used in oil pipelining it was necessary to use such a pump here. A shallow-well water pump seemed satisfactory - it is called a Duro twin-piston pump, Model E720. In early tests it pumped 50.9 L/min water or 53.04 L/min sweet crude oil of viscosity 3.87 cp at 21°C. Further specifications are given in Appendix C.

2.2 FOR THE CENTRIFUGING TESTS

A sketch diagram of the layout is shown in Figure 2.

The reservoirs for feed were 204.5 litre drums which had had nipples welded on just above their bases. Two feed reservoirs were used because one peristaltic pump would not span the range of feed rates, 0.1 to 10 L/min, to be used, so two pumps were needed.

The Bird continuous screen-bowl centrifuge is shown diagrammatically in Fig. 3. The unit used conformed to the specifications, other than screen openings, set forth in Table 1 of Appendix A (page 63). It is essentially a horizontal cylinder rotated by a motor through V-belt drive. Within it is a screw conveyor with a slight differential rotation given by a gearbox; its function is to scrape the solids to the solids discharge. Towards the discharge end of the centrifuge the cylinder is perforated with 0.305 mm holes - this is the screen - and a slurry of the smaller solids comes out of this screen as middling. The other end of

the cylinder is flared, then ends abruptly in a wall. In this wall are holes, the pool depth ports, of varying distance from the axis, into which are threaded solid or perforated plugs. The object of these ports is to govern the depth of liquid in the centrifuge when running. In this work the pool was kept as deep as possible (1.23 cm) to make for a better settled product liquid. Feed slurry is introduced through an axial pipe at the non-driven end; the feed may be released at various positions. It was thought better to release the feed as far in as possible.

The major complications of the Bird screen-bowl centrifuge are the screen and product wash devices. The screen wash washes the screen from outside, the product wash is to wash the screen from within. In this work product washing was omitted. It would have been desirable not to bother with the screen wash either, but it was very soon found that if screen wash is omitted, any or all of the following harmful phenomena will take place: i) plugging of the screen with solids; ii) grinding and snapping sounds out of the machine indicating wear; iii) heating of the discharge end of the centrifuge with release of blue smoke from the breather.

The speed of the centrifuge was measured with a stroboscope. Gravitational accelerations were obtained from these speeds by means of a graph in the Bird instruction book. Centrifuge speed may be altered by changing sheaves on its belt drive.

2.3 COALS AND OIL USED

The coals used in the project were run of mine material from:

i. Sundance mine, Wabamun, Alberta - a thermal coal

ii. Vesta mine, Halkirk, Alberta - another thermal coal

iii. McIntyre - Porcupine mine, Grand Cache, Alberta - the metallurgical coal.

Sufficient amounts of these were obtained at the mines and hauled to Birtley Coal and Mineral Testing, Calgary, Alberta, for two-stage grinding with hammermill and muller. The McIntyre metallurgical coal was dried there as its water content was to be below 7%. This was done by floor drying at 35°C. Specified water contents on the thermal coal were generous enough that no drying was needed. Particle size distributions of these ground products appear in Table 1.

For the Sundance coal the percentage below 325 mesh was reported as (see Table 1), 20.6. The directives called for the percentage of fines to be not more than 15%; 20.6% was too much. Another sample of Sundance coal was obtained and transported to Birtley in Calgary for them to make another attempt at grinding it to specifications. This second sample appears under the name "Wabamun" in Table 1 and thenceforward.

Values of water content and density for these coals appear in Table 2.

The synthetic crude sample was obtained through Dr. McIlroy of the B.C. Research Council from Interprovincal Pipeline Ltd. Its density was measured here as 0.862 g/ml at 21°C with Westphal balance, and its viscosity by Brookfield viscometer with U L adaptor as 3.8 cp at 21°C.

3 PROCEDURE

3.1 SLURRY MAKING

The first step in slurry making was to weigh out the coal and the oil. The oil was put in the conical-bottomed mixing tank and circulated with the Duro pump. Then the coal was added in quantities of about 1/2 kg. If the coal be added all at once or in large portions, the pipe at the base of the tank will plug. The slurry is highly settling, and considerable experimentation with the physical arrangement of stirrer and baffle was needed to keep the coal suspended in the oil without plugging pipes.

3.2 ATTRITION RUNS

The slurry upon being made must next be circulated through the pump and back into the tank to simulate pipeline travel.

Determination of circulation time starts from the assumption that degradation of the solids takes place mainly through mechanical abuse in going through the pump rather than by interparticle and particle-to-wall collisions in the line. (This assumption seems widely held in slurry pipelining, but it appears not to have been experimentally demonstrated). Then if an assumed 3000 km pipeline to Eastern Canada has the 80 km spacing between pumping stations required by considerations of pressure drop, it must have 37.5 pumping stations. For a safety margin 40 stations were assumed. Thus the experimental slurry must go through the pump 40 times to undergo as much abrasion in the pump as in a real pipeline.

If 250 kg of coal-oil slurry of density 1.02-1.05g/mL is pumped with a pump which can move about 40 L/min, the time needed for 40 passes is about 4 hrs. Besides varying with the amount of slurry on hand, this time would vary somewhat with slurry density and the rate the pump was achieving at the time.

3.3 CENTRIFUGING RUNS

The circulated slurry was pumped with the Duro pump into the two feed reservoirs of Figure 2, one for each Peri pump.

These 204.5 litre reservoirs also required Lightnin' mixers and baffles to keep their contents suspended and approaching homogeneity.

Operating the Bird centrifuge was relatively simple except for the complication of a screen wash. The machine was switched on and allowed to get up to speed, which took about two minutes. Then the chosen peristaltic pump feeding it was started and in a brief while liquid and solid products as well as middlings slime would be coming out the appropriate exits. The time required to reach equilibrium was uncertain, especially when frugality in the use of raw materials was necessary. After half a minute to a minute things usually seemed to approach equilibrium at feed rates over 1 L/min. At the lowest feed rates a much longer wait was needed; at 0.1 L/min it took 20 min before coal granules began to come out of the solids port.

While centrifuging, timed weighed samples of liquid product, middlings and solids were taken, as close together in time as possible, for calculation of production rate and for finding the solids content and P.S.D. by analysis.

Task 2 and Task 4 centrifugations did not differ in procedure other than that a Task 4 centrifugation took longer.

4 METHODS OF ANALYSIS

4.1 SIEVING

In the tender for the proposed project, it was assumed that particle size distribution could be done by dry sieving after washing out the oil from the coal with Iosol or some such low-boiling petroleum solvent. Examination of the -325 mesh in any convenient fluid could be done by Sedigraph.

Matters in reality turned out otherwise. Attempts were made to release the coal from the oil by wetting it by a simple Iosol wash. However, on sieving, the finer material, from about 35 mesh down, was found to be agglomerated in oily little balls, and distributed in various coarser size ranges than its individual particles.

After unsuccessful experimentation with washes by one or another solvent it was decided to recover the solids using the method of E76-3 (1).

In this method, samples of about 150 g were weighed out, diluted with Iosol and centrifuged in a basket centrifuge lined with a strip of Reeve Angel #230 filter paper. The solids on the paper were washed successively with Iosol and with Chlorothene (1,1,1-trichloroethane from Harrisons & Crosfield). These organic solvents are supposed to wash away the oil. To some extent the very finest solids always pass through the filter paper. Severe cases of this are designated "effluent colloidal" in the result tables. This happened with several liquid samples. Presumably these are submicron fines.

Then the cake on the filter paper was washed with stock solutions in water of "Ajax", an oxidizing detergent, and "Arctic Syntex", which has been described as a "mild industrial detergent". Stock solutions of

these detergents must be prepared beforehand as both are supplied as solids and Ajax contains pumice which must be settled out. These remove the organic solvents. A final hot water wash was to remove the detergents.

The cake can then be dried at 75 - 80°C (to lessen air oxidation) and weighed. To get the percentage of wet coal in the original sample the water lost by drying must be added. This can be obtained from the dry-basis water content.

The dry cake is then screened in water through a 325 mesh sieve to separate the minus 325 fines. The plus 325 is then dried, reweighed and subjected to conventional dry sieving with a Ro-Tap device to get its particle size distribution.

4.2 SUBSIEVE PARTICLE SIZE DISTRIBUTION BY SEDIGRAPH (R)

It had been intended to obtain the particle size distribution of the minus 325 mesh fines from every analyzed sample by means of the Sedigraph (trade mark) from Micromeritics Inc. This machine performs sedimentation analyses automatically and rapidly; its fundamental principle is the same as that of the familiar Andreasen pipette, namely, Stokes' law. As with said pipette, the density and viscosity of the suspending fluid must be closely known.

It had been thought that if the Iosol (naphtha) removed the oil from the coal in a sample, it should be possible to run the -325 coal in the Sedigraph using any convenient liquid dispersing medium. But a plain naphtha wash didn't wholly free the coal particles.

Numerous experimental difficulties were encountered trying to determine by Sedigraph the P.S.D. of the -325 mesh fines obtained by the method

of E76-3 (1). A procedure was worked out for dispersing the coal fines in methanol, filtering under suction, redispersing the solids in more methanol, and subjecting this dispersion to examination in the Sedigraph. This procedure worked after a fashion for a few determinations, but soon the machine began to function erratically. This was traced to the deposition of a thin film of gum or other polymer on the walls of the cell of the Sedigraph from the coal dispersions circulated through it. It was decided that if the cell itself was being harmed no more Sedigrams were to be done. By then, enough results had been obtained from the Sedigraph to permit conclusions to be drawn about the sub-sieve particle size disribution of the solids.

4.3 MOISTURE CONTENTS OF COALS AND CENTRIFUGE PRODUCTS

For an unoiled coal the water content could be found simply enough by drying at 75 - 80°C.

For determining the water content of coal samples that had contacted oil the apparatus and method originally envisaged did not work. It had been intended to use the Speedy Moisture Meter (from Thomas Ashworth Ltd., Burnley, Lancashire), which, according to its advertisements, had successfully determined moisture in numerous commercial products. It works by reacting the sample with CaC_2 and measuring the pressure of acetylene produced. It did not work at all well for oily coals, ordinarily finding 30 or 40% of the water known to be present. Consequently we were forced in computing the weight percent of wet coal in an oily product to assume that the original moisture as measured by drying was still there. This was proved to be a sound assumption by taking a few specimens of oily products and equilibrating them with P_2O_5 in a heated desiccator.

5 RESULTS

5.1 WABAMUN COAL, TASKS 2 & 3

From the Wabamun coal and synthetic crude oil 360 L (375 kg) of 45 wt % solids slurry were made up in two subequal batches. The first batch was circulated 5.5 hours, twice as long as it should have been, the second batch 3 hr. 7 min., the correct time for 40 passes. In Table 3 analysis 5 is that of the solids in the second batch of slurry just after mixing, and analysis 6 is that of these solids after the three hours of circulation. Analyses 8 and 9 are of the solids in the mixture of the two batches just before centrifuging.

A sieve analysis of the original dry coal is given as analysis 7 in Table 3.

Upon this Wabamun slurry centrifugings were performed as follows:

775 gravities acceleration (3050 r.p.m.); feed rates 0.52 and 7.33 L/min.

1000 gravities acceleration (3510 r.p.m.); feed rates 0.13, 0.49, 1.08, 2.5, 5.3, 7.63, and 10.36 L/min.

1505 gravities acceleration (4225 r.p.m.); feed rates 0.5 and 7.5 L/min.

Details of product flow rates at these conditions and a mass balance per minute appear in Table 4. Calculation of the proportions among products is given in Table 5. Particle size distributions of the solids in all solid products appear in Table 6. Table 7 gives PSD's for the solid part of the middlings from tests run at 0.5 and 7.5 L/min. Table 8 gives the PSD's of the solids in the liquid products from tests at these feed rates.

5.2 VESTA COAL TASKS 2 & 3

For the 45% slurry of the Vesta thermal coal, 114.3 kg of coal and 139.7

kg of synthetic crude oil were weighed out and a slurry made from them. After addition of the coal the pump was found to be moving a slurry of density 1.02 g/mL at a flow rate of 38.93 L/min. Hence for the 40 passes needed to simulate pipeline transportation the slurry ought to be circulated for 4.26 hours.

The slurry was circulated for 4.23 hours without incident. Samples for particle size determination were taken from the slurry immediately after mixing (analysis 47, Table 9) and also at the end of circulation (analysis 48, Table 9). The results of these determinations showed so much less - 325 than Birtley had reported (Table 1) that a checking of their results was needed. Both barrels in stock of dry ground coal were carefully sampled and PSD's done on these samples, with results as shown on Table 9 as analyses 46 and 46 1/2.

On the Vesta slurries centrifuging runs were carried out at the same gravities of acceleration as for Wabamun coal, and with feed rates as near to those for the Wabamun slurries as the peristaltic pumps would permit. Conditions and product flow rates, with a mass balance, are enumerated in Table 10. Screen plugging occurred twice. This is because 105 mL/min of screen wash is not really enough to keep the screen well cleaned, but any higher wash rate would interfere with the observation of trends at low centrifuge feed rates. Table 11 gives the relative proportions of these products.

Particle size distributions of the solids in all solid products appear in Table 12. For the middlings at 0.5 and 7.5 L/min the P.S.D. of the contained solids appear in Table 13; the same thing for the liquid products appears in Table 14.

5.3 MCINTYRE COAL, TASKS 2 & 3

This time a 50% by weight slurry of coal and oil was called for. In order to make 360 L slurry, 190.5 kg McIntyre coal and 190.5 kg synthetic crude oil were weighed out. During slurry making the pump failed because its rubber valves had been attacked by oil. With new neoprene valves the flow rate of the pump was at first much less, then slowly increased from wearing in of the valves. For every measured flow rate the circulation time remaining had to be recalculated. The total circulation time came to 6.5 hours.

Samples for particle size distribution and solids content on dry and wet (oiled) heads were taken. The results appear in Table 15.

Details of the centrifuging runs on slurries of McIntyre coal appear in Table 16. This table contains the feed rates, multiples of gravitational acceleration G, product flow rates, and solids content of the products, as well as attempted mass balances for each centrifugation on a 1-minute basis. For McIntyre slurries two variations in procedure were added to the schedule:

1. Screen wash, using surplus liquid product, was tried out at 250 mL/min (215.5 g/min) as well as at the usual 105 mL/min (90 g/min).

Centrifugings featuring this higher rate of screen wash are marked "H" in the result table, Table 16.

2. Centrifugings featuring recycle of the middlings stream back to the feed end, as suggested in the contract. There seemed no point to recycling less than all the middlings. The recycled middlings were put in the screen wash ports. Centrifugings with middlings recycle have been marked with an "R" in Table 16.

Percentage distribution of the outgoing material among solid, middling and liquid products is shown in Table 17.

Percentage size distributions of the solid fraction of all solid products appears in Table 18. The P.S.D. of the solids at 0.5 and 7.5 L/min feed rates is given for the middlings in Table 19 and for the liquid products in Table 20.

5.4 TASK 4; CENTRIFUGINGS OF TEST QUANTITIES OF PRODUCTS FROM ALL THREE COAL SLURRIES

Conditions for Task 4 were set by the Scientific Authority.

These were:

Slurry of Wabamun coal: 0.5, 4.0, and 7.5 kg/min.

Slurry of Vesta coal: 0.5, 1.0, 4.0, and 7.5 kg/min.

Slurry of McIntyre coal: 0.5, 1.0, 4.0, and 7.5 kg/min.

All these were to be done at 1000 G acceleration.

No recycle was to be used. The products from the screen-bowl centrifuge with recycle had been unsatisfactory.

Twenty litres of liquid product were to be made for each centrifuging and whatever amount of solid product reported was to be accepted. Per 20 L liquid it was found that a somewhat greater volume of oily solid product was obtained, likely due to entrained air. Since 22.7 litre cans, lacquered within, were readily available as shipping containers, it was decided to collect one full can of solid product for each run. Any excess quantity of solid product was put into a composite can, which received the leftovers from all feed rates on that particular coal. Hence Dr. McElroy of B.C. Research received 11 cans of solid product, one for each of the runs, and 3 extra cans which contained only one coal but material from all feed rates.

It had originally been intended to use 250 mL/min screen wash in all centrifugings to lessen the risk of screen plugging in long runs. However at the lower feed rates of 0.5 and 1 L/min, this was found impractical for

simple reasons of mass balance. For the 0.5 L/min feed rate, it was necessary to cut the screen wash down to 50 mL/min; at 1 L/min feed, screen wash was set at 100 mL/min. (With some one percent of coal in it, the density of liquid product was little different from that of synthetic crude oil which was 0.862 g/mL at 20°C; for liquid product a density of 0.856 g/mL at 27°C was measured by hydrometer).

At 50 mL/min screen wash screen performance was barely satisfactory, it kept plugging and relieving itself. At any feed rate screen plugging was always a possibility; the discordant figures for Vesta coal slurries at 4 L/min (Table 22) suggest that the samples were taken during an occurrence of partial screen plugging. Each centrifuging was started off with 2L of fresh crude oil for screen wash. When this was used up, liquid product was diverted for the purpose.

Enough Wabamun 45% coal-in-oil slurry remained from Task 2, so that no more had to be made. Fresh slurries in oil were made up by weight for Vesta and McIntyre coals and circulated the 40 trips through the pump and tank.

For Vesta coal some 250 L of slurry were made and the attrition run took about 4 1/2 hr. For McIntyre some 230 L were made up new. Its attrition run took about 3 hr 20 min.; then 60 L of old slurry left over from Task 2 were added to it and mixed.

As in Task 2, timed samples for analysis of solids content and particle size distribution were taken. The results of analyses of these samples appear in Table 21.

Conditions of centrifuging and product flow rates in Task 4 are summarized in Table 22. The last 3 columns give a mass balance on a per

minute basis; this should give some idea about whether or not equilibrium was nearly attained, at least at the time of sampling.

A summary of the proportions of the products to one another for Task 4 centrifugings appears in Table 23.

The particle size distributions of the coal in the solid products from the Task 4 centrifugings are shown in Table 24, for the middlings these P.S.D.'s appear in Table 25, and for the coal in the liquid products these values appear in Table 26.

5.5 RESULTS FROM THE SEDIGRAPH; EXISTENCE OF SUBSIEVE FINES

The few subsieve particle size determinations which were done with the Sedigraph (trade mark) showed plainly that the distributions did not cut off sharply anywhere above 1 μm. Continuous smooth distribution curves levelling off somewhere about 1μm were instead obtained. Specific results for the samples run before the windows gummed up read thus:

#48, Vesta, end of attrition. Ran from 50 to 0.5 μm, little under 1 μm

#49, Vesta, high rate centrifuge feed. Ran 50 - 0.5 μm, nothing smaller than 0.6 μm.

#53, Vesta 775G, 0.53 L/min, liquid product. Ran 40 - 0.3 μm, essentially all 25 μm to 1 μm.

#56, Vesta 775 G, 7.7 L/min, liquid product. Ran 50 - 0.4 μm, all above 1 μm.

#60, Vesta 1000G, 0.5 L/min, solids. Ran 50 - 0.6 μm, particles present at least to 0.8 μm.

#61, Vesta 1000G, 0.5 L/min, middlings. Ran 50 - 0.3 μm, nothing below about 0.6 μm.

#84, Vesta 1500G, 7.7 L/min, solids. Ran 50 - 1 μm, little below 1.5 μm.

#85, Vesta 1500G, 7.7 L/min, middlings. Ran 50 - 0.5 μm, little or nothing below 0.8 μm.

These samples were chosen at random from among the sample containers on the desk, so no significance is to be attached to which of them were done. The original idea had been to determine the subsieve particle size distribution of all -325 mesh coal samples with the Sedigraph, before the program was stopped from damage to the machine.

5.6 WATER CONTENT OF OILED COALS BY P_2O_5 ABSORPTION

Three trials were made in which a known weight of coal or slurry was shut up with a known weight of P_2O_5 in a closed desiccator and this was heated at 80 - 85°C overnight in an oven. The weight pickup of the P_2O_5 must be corrected for the quantity of water in the air in the desiccator.

Results are shown in Table 27.

6 DISCUSSION OF SPECIFIC RESULT TABLES

6.1 WABAMUN, TASKS 2 & 3

i. Table 3. The dry heads particle size distribution of Wabamun coal shows a minimum in the -80 + 100 mesh class and a secondary maximum in the -100 + 150 mesh class which persists in the oil slurry and in the solid and middling centrifuge products derived therefrom. The other coals behave similarly. This is an artifact of Birtley's two-stage grinding.

The evidence for degradation of the Wabamun coal in pipelining is inconclusive. Analyses 5 and 6 of Table 3 claim that degradation took place in that the fines content went up from 14.1 to 16.37%. However, analyses 8 and 9 (Table 3) contradict this, showing values of 11 or 12% for -325 fines, somewhat lower even than the dry heads figure of 13.69%. The question is obscured by the observation that a 2% (of total) discrepancy in fines content between like samples is not uncommon in this method of analysis.

Mass balances on the -325 fines before and after all three 0.5 and 7.5 L/min centrifugings on the Wabamun slurry were tried in hope that it would be possible to choose between values of fines content in the feed. The three 0.5 L/min centrifugings agreed in accounting for enough fines to correspond with a fines content in the feed of about 15%. The three 7.5 L/min tests accounted for fines in amounts as if the slurry had contained 13 or 14% fines.

The only sense that can be made of the variation of fines content among the analyses in Table 3 is to assume that the determinable fines content lessens with aging the slurry, perhaps due to gum deposition. This lessening was observed for Wabamun and McIntyre coals also in Task 4. If so, it may be concluded from analyses 5 and 6 that some degradation took place in Wabamun coal slurries on circulating.

ii. Table 4. This table for Wabamun shows that 1) the percent solids in the solid product is 90 - 95% without apparent trend with feed rate or centrifuge speed; 2) the solids in the liquid product amount to 0.5 - 2%; 3) the percent solids in the middling runs 30 - 45%, seemingly increasing at high feed rates; 4) at the lowest feed rate of 0.13 L/min the 105 mL/min recirculated liquid product acting as screen wash results in a large middling flow of 94.2 g/min, low in solids.

The calculated excess or deficit of outgo over feed plus screen wash is some test of whether equilibrium was attained. It is thought that budgets less than 10% off balance are satisfactory, as the standard deviation of all values for % mass budget misbalance is 12.6%.

iii. Table 5. At feed rates above 2.5 L/min the solid and liquid product flows are roughly equal at 40 - 45% and the middling, or screen outgo, is some 16% of the products. As feed rates decrease the middling

increases, presumably because only so much slurry can flow through the holes in the screen in unit time, and if the slurry feed decreases, that which can flow through the screen is a larger proportion of the total flow. At 0.13 L/min feed the flow of solids large enough to avoid going through the screen is small with respect to the middlings and liquid, because the mass being treated is half screen wash, i.e. old liquid product.

iv. Table 6. Except for the entry for 1000 G and 0.13 L/min, the particle size distributions of the solids in the solid product appear about the same, without trends. The holes in the centrifuge screen being 0.305 mm or 48 Tyler mesh, these solids are enriched above 35 mesh and depleted below 65 mesh with respect to the feed (Table 3). All the +48 mesh is held back by the screen but not all the -48 mesh goes through the screen, much is prevented from getting through by a bed of +48 mesh on the screen. For the 0.13 L/min centrifugation, the coarse solids being scanty, they were relatively well washed by the 105 ml/min screen wash and the -48 mesh is much reduced compared to the higher feed rates.

v. Table 7. About all that can be said of the particle size distribution of the solids in the middlings from the Wabamun centrifugations is that the deficit in minus 48 mesh between the feed and the solid product reports here. The middlings run about 30% minus 325 mesh fines.

vi. Table 8. The solids in the liquid products from Wabamun centrifugations runs 50 - 90% minus 325 mesh fines. That's all that can be said, for the total weight of solids recovered in an analysis was of the order of 0.5 - 1 gram, meaning that a fraction caught on a sieve might weigh some 10 to 100 milligrams, and the weighing error might easily

be 100% or more. Also just a few coarse coal grains finding their way into the liquid sample while centrifuging would skew the particle size distribution seriously.

6.2 VESTA, TASKS 2 & 3

i. Table 9. The item of interest in the P.S.D.'s of Vesta Coal is how much more fines Birtley got than in the local measurements. The analyses of Table 9 agree in finding 1 - 3% minus 325 where Birtley reported nearly 15%. They must have taken some unrepresentative sample of this grist.

It is fairly plain that 1) Vesta coal must be harder than Wabamun coal, as Vesta exceeds Wabamun in the largest three size classes, and is very much lower in -325 fines; 2) no degradation by simulated pipelining has taken place, as the -325 varies from 1 to 3% without trend in circumstances.

ii. Table 10. This gives the details and circumstances for the centrifugings on the Vesta slurries. Most of what was said about Table 4, Wabamun, may be repeated here - the solid product runs 90 - 95% coal, the middlings about 35% coal, and the liquid product about 0.5 - 1% coal without clear-cut effects of centrifuge speed or feed rate.

iii. Table 11. The relative distribution of the products among themselves on centrifuging Vesta coal slurries shows the same trends as for Wabamun coal slurries.

iv. Table 12. The particle size distributions of solids in the solid product from centrifuging Vesta coal slurries shows the same trends as for Wabamun coal slurries - all just about the same except at the 0.11

L/min feed rate where relatively better washing cleaned the -48 mesh material more effectively out of the solids on the screen.

v. Table 13. The PSD of the solids in Vesta middlings show the same features as those in Wabamun middlings - very little above 48 mesh, an 80 or 100 mesh minimum and a 150 mesh maximum. There does seem to be an effect of feed rate here, in that samples produced at the high feed rate seem to be richer in minus 100 mesh material than those produced at the low feed rate. This effect is seen for the other coals, but less plainly. The explanation is just this: the higher the feed rate, the more the finest particles are differentially favoured to get through the screen.

vi. Table 14. The particle size determinations of the solids in the liquid products from centrifuging Vesta slurries are erratic. The experimental errors are caused by taking the small difference of two large quantitites while weighing the fractions along with slight variable and erratic contamination of liquid by solids in the centrifuge. Probably 90% below 325 mesh would be a realistic guess at the actual conditions that hold most of the time.

Trial mass balances on the quantity of -325 mesh Vesta coal going into and coming out of the centrifuge show that the figure 3% for the fines in Vesta (analyses 46, 49, 50 Table 9) is a better value than 1%.

6.3 MCINTYRE, TASKS 2 & 3

i. Table 15. The particle size determinations on the McIntyre coal at various stages show that there is degradation by attrition here, even with all the variance inherent in the method of determination.

ii. Table 16. This summary of events on centrifuging McIntyre coal slurries shows: 1) solids with the usual 90 - 92% coal; 2) middlings

tending to be higher in coal, often 45 - 50%; 3) liquids at 7.5 L/min feed with some 4% coal solids. The last two items are probably results of the high fines content of this coal. Recycle at either low or high feed rates makes for bad matter balances and high coal content in the liquid because the fines must go somewhere. High screen wash at the low 0.51 L/min feed rate gives lower solids in the middlings because more of the middling is screen wash. At 7.5 L/min feed an increase of screen wash from 100 to 250 ml/min is an insignificant increase.

iii. Table 17. As concerns the mutual proportions of the products from centrifuging McIntyre coal slurries, when recycle of middlings takes place the mass shows up mainly in the solid product rather than in the liquid. Without recycle the middlings represent a progressively smaller proportion of the mass going out as the feed rate increases, as usual. The liquid seems to weigh 2/3 - 3/4 as much as the solid product, unlike the tests with the other coals wherein the liquid weighed about the same as the solid. High screen wash at 0.49 L/min feed increased the proportion of middlings; at 7.59 L/min the screen wash was small compared with the feed so that high screen wash had no visible effect on product distribution.

iv. Table 18. The particle size distributions of the solids from centrifuging McIntyre coal slurries shows nothing not already known. With full recycle of middlings there ought to be more fines in the solid product. At 0.49 L/min this looks to be borne out by experiment, but at 7.59 L/min one cannot really discern such an effect.

v. Table 19, The particle size distributions of the middlings from the McIntyre runs are all about the same except for the sample caught

out of the middlings (screen wash) under recycle. This recycle stream has solids with a reading of 62% minus 325 fines, perhaps because plus 325 gets differentially filtered out on the filter cake on the screen and reports in the solid product.

vi. Table 20. This gives the particle size distributions of the solids in the liquid product from McIntyre centrifugings. As usual they run 80 - 98% minus 325 fines except for two at 50% fines, possibly caused by internal contamination as suggested earlier.

Mass balances on the incoming and outgoing minus 325 mesh coal (not the whole coal) were tried for McIntyre coal slurries at 7.45 L/min and 1500 G, 7.59 L/min and 1000 G, and 7.7 L/min and 775 G - these centrifugings had yielded good overall matter balances. In all three cases about 750 g/min minus 325 mesh came in and 850 - 900 g/min came out. This suggests either the 15 - 17% fines in the circulated feed (Table 15) is wrong - the true value being some 19.5 - 21% - or that fines are being created in the centrifuge. The latter is a little more believable.

6.4 TASK 4 CENTRIFUGINGS

i. Table 21. This shows the initial solids content and P.S.D. for the Task 4 slurries. The Vesta slurry is essentially a repeat of that used in Task 2 (Table 9). The Wabamun slurry (old stock) seems greatly depleted in fines compared with its former values in Table 3. This depletion may be explained by postulating a cementing together of the fines in storage by gum in the oil such as that which deposited on the window of the Sedigraph. A decrease in fines content on aging is also shown in the McIntyre slurry used in this task. Here new slurry was made up and the fines content increased on carrying out the attrition

run, then a portion of old slurry was added and the fines content lessened again.

ii. Table 22. The numerical values obtained from the Task 4 centrifugings are about the same as for similar circumstances in Tables 4, 10, and 16. Comparisons fail when one of the tests being compared is far off mass balance.

The best liquid product, about 0.5% coal, was made with Vesta coal slurry as feed, perhaps because Vesta coal had less fines in it to begin with. At least this was observed for 3 feed rates; there is something wrong with Vesta at 4 L/min. Here the coal content of the liquid is high, 10%, and that of the solid is low, 91%, while the mass balance is poor. Perhaps screen plugging was just beginning at the time of sampling. McIntyre coal gives middlings higher in solids than the other coals.

Similarly the product proportions found in Task 4 centrifugings (Table 23) show no new trends.

iii. Table 24. This gives details of the measured particle size distribution of the coal in the solid products of Task 4. A few random extreme values are seen but no regular trends with feed rate. The same may be said of Table 25 of the P.S.D. of the coal in the middlings. Table 26 gives the P.S.D. of the coal in the liquid product and here as for other liquid products, the effect of random contamination by a little coal of a liquid product normally containing 0.5 to 3% solids which are normally 85 - 95% below 325 mesh is the main thing shown by the numerical data.

6.5 SEDIGRAPH RESULTS

The fragmentary results obtained with the Sedigraph show that the particle size distributions go on below 325 mesh to at least 1 μm. There

is really no reason for the P.S.D. to cease at 1 μm; likely the submicron particles went on through the basket centrifuge. These Sedigraph results were obtained with Vesta coal low in fines. The other two coals higher in fines and with more evidence of size degradation during circulation would be expected to have similar continuous particle size distributions down to and beyond 1 mμ.

6.6 MOISTURE CONTENT OF OILED COALS

Probably the absorption of water by P_2O_5 in a heated 80 - 85°C enclosure as shown by Table 27 worked because the vapor pressure of water was increased enough for the water to boil off regardless of the obstructing oil films.

6.7 COMMENTS ON OVERALL RESULTS

i. Change of feed rate and of centrifuge speed have little effect on the particle size distribution of the solid contained in a product. These changes do affect the proportion of the three products to one another and to a lesser extent the percent coal in a product.

ii. Screen plugging seemed to occur almost randomly and examples were encountered at every wash fluid feed rate used - 50, 105, or 250 ml/min. Maybe the centrifuge designers contemplated screen washes of the order of 1 L/min or more. Fairly plainly the centrifuge is made to work best at or near the stated design capacity of 10 USGPM = 40 L/min, as was seen from the fact that operation was much more satisfactory at the high feed rates of 7.5 and 10 L/min. The better mass balances at such feed rates testify to this also.

iii. In Tables 3, 9, 14 and 21, there always seems to be a higher solids content by analysis than the slurry was made up to have. There must have been light ends to lose. Imperial Oil's analytical results in Appendix B show that light ends were lost. It is not apparent what could be done

about this. Covered tanks could have been used, but the breather of the centrifuge must be kept open.

iv. In retrospect it would appear that a solid bowl centrifuge would have been better than a screen bowl centrifuge. In a solid-bowl centrifuge there is no screen. Hence the solids from 0.305 mm down would show up in the solid product. The solid product would probably be higher in oil than that from a screen-bowl centrifuge, because of its greater specific surface. However, the liquid product would likely be no worse with a solid-bowl centrifuge than with a screen, at least at high feed rates, judging by the figures for McIntyre coal slurries at 7.59 L/min with and without recycle (Table 16). A screen-bowl centrifuge is made to produce a clean solid product with minimum particle size that of the holes and does not concern itself with purity of the liquid.

v. The writers are not qualified to discuss Imperial Oil's analytical results.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

1) Rather poor separation of the components was achieved by centrifuging coal-in-oil slurries with the continuous screen-bowl centrifuge. The speed of the centrifuge made no consistent difference in the results, and slurry feed rate made little difference above about 0.5 L/min.

2) Degradation in size of at least one, and likely two, of the coals was shown to have occurred on simulated pipelining. The production here of subsieve and submicron fines is likely to be both more harmful to separation and also harder to confirm experimentally than the mere shifting of particle size distribution peaks down the sieve scale.

7.2 RECOMMENDATIONS

Should any further work be done the following suggestions are made:

1) A solid bowl centrifuge should be used. The experimental complications are fewer and the results would likely be no worse.

2) Flow rates in the middle of the working range of the centrifuge should be used, as 10 - 20 L/min for a machine with design capacity 4 - 40 L/min.

3) The whole subject of particle size distribution requires intensive study. The method of E76-3 used here is too erratic in results and visibly loses some colloidal material. In the + 325 range, four or five sieves would be ample to keep track of any changes in P.S.D. affecting performance; the phenomena of critical meaning for separation of oil and its refining occur down in the minus 325 size range. The undisturbed PSD spectrum of the minus 325 mesh fines before and after both pipelining and centrifuging ought to be obtained. The writer suggests as a starting

point for study the Soxhlet extraction of oiled coals with organic solvents to see whether the coal can be freed of oil and adsorbed matter before sieving or sedigraphing.

4) If synthetic crude contains something, perhaps a gum, which alters the particle size distribution of coal slurries in it on standing, the use of a natural crude is suggested if further studies are undertaken.

5) If the water content of samples from the centrifuge absolutely must be known, a microwave moisture meter would seem appropriate under conditions of the water being shut up inside coal particles by oil films.

8 REFERENCE

1) "Experimental Studies on the Pipelining of Coal-in-Oil Slurries" L.G. Smith, W.H.W. Husband, D. Haas, A. Richardson. Report E 76-3 Engineering Division, Saskatchewan Research Council to Transport Development Agency, Ministry of Transport, 17 March 1976.

9 TABLES

Table 1

Birtley's P.S.D.'s by Wet Screening of Coals, in wt%

Coal Retained on Tyler Mesh	Sundance	Vesta	McIntyre	Wabamun
14	8.5	6.6	3.4	0
28	32.1	38.0	23.2	35.1
48	20.4	21.5	21.7	23.7
100	10.4	11.8	16.1	14.6
200	5.7	5.6	11.7	8.7
325	2.3	1.6	5.3	4.6
-325	20.6	14.9	18.6	13.3

Table 2

Water Contents and Densities of Coals Used

Coal	% water, wet basis	Dry density, g/mL	Wet density, g/mL (Calculated)
Sundance	16.76, 16.38		
Vesta	20.55, 20.97, 21.21, 21.40	1.482	1.346
McIntyre	2.61, 2.44, 2.52, 2.66	1.367	1.354
Wabamun	17.25, 16.84	1.534	1.415

Table 3

Particle Size Distributions of Feed, Wabamun Coal Expt.

Retained on Tyler Mesh	#7 Dry Head Moisture 20.45% w.b. %	#5 Wet Head Before Attrition 50.52% solids %	#6 Wet Head After Attrition 49.79% %	#9 Wet Head from barrel feeding high flow pump; 48.19% by wt. solids %	#8 Wet Head from barrel feeding low flow rate pump; 49.20% solids %
14	0.67	0.85	0.48	0.93	0.93
20	6.63	8.08	5.61	8.23	8.21
28	15.89	17.22	15.46	16.78	17.46
35	14.15	14.31	13.92	15.45	14.14
48	14.54	13.72	14.18	13.4	13.77
65	10.73	10.98	11.42	10.87	11.26
80	4.5	3.84	4.39	4.53	4.18
100	4.0	3.61	3.6	3.79	3.74
150	6.0	5.37	5.52	5.79	5.63
200	4.9	4.14	4.79	4.69	4.61
325	4.28	3.77	4.23	4.41	4.37
-325	13.69	14.10	16.37	11.12	11.69

Table 4

Bird Centrifugings on Wabamun Coal Slurry, 45% Coal by wt. (nominal)

Coal, Dry ρ = 1.534 g/mL, 20.25% H_2O d.b. Oil, ρ = 0.862 g/mL @ 21°C Density Slurry 1.04 g/mL (measured)

Gravitational Accelerations	Feed Rate to Centrifuge w/o wash of 105 mL/min. or 90 g/min. L/min.	kg/min.	Solid Product Output Rate g/min.	% Solids	Middlings Output g/min.	% Solids	Liquid Product Output g/min.	% Solids	Mass Balance per Minute Income kg	Outgo kg	Relationship of Outgo to Income based on Income
775	0.52	0.54	232	97.56	275.0	30.85	195.9	0.37	0.61	0.7029	Over 15.2%
(3050 rpm)											
	7.33	7.62	4191	91.39	1607.5	40.08	3032.7	3.22	7.71	8.83	Over 14.5%
1000	0.13	0.135	28.64	95.99	94.2	20.27	63.6	2.18	0.225	0.186	Short 17.3%
(3510 rpm)	0.49	0.51	187.08	93.93	236.6	36.11	212.8	1.14	0.60	0.636	Over 6%
	1.08	1.12	423.4	88.97	367.8	n.d.	441.8	n.d.	1.21	1.233	Over 2%
	2.5	2.6	1108.4	92.78	734.7	n.d.	1117.2	n.d.	2.69	2.96	Over 10%
	5.3	5.51	2295	92.30	960.3	n.d.	2176.8	n.d.	5.60	5.43	Short 3%
	7.63	7.935	2918.8	94.35	1188.8	42.62	2682	1.83	7.72	6.79	Short 12%
	10.36	10.77	4432	92.04	1871.2	n.d.	4242	n.d.	10.86	10.54	Short 3%
1505	0.5	0.52	178.9	97.86	264.5	39.93	221.1	0.48	0.61	0.664	Over 9%
(4250 rpm)	7.5	7.8	3455.7	92.04	1442.1	45.63	3288	1.91	7.89	8.18	Over 4%

Table 5

Distribution of Centrifuge Products From Wabamun Coal Slurries

Gravitational Accelerations	Feed Rate L/min	Percent of Output		
		Solids	Middling	Liquid
775	.5	32.21	37.94	29.85
	7.5	41.69	25.12	33.19
1,000	.1	17.53	41.23	41.24
	.49	25.29	43.30	31.41
	1.0	33.69	27.06	39.25
	2.5	36.72	22.53	40.75
	5.3	43.37	16.63	40.00
	7.6	42.37	15.50	42.13
	10.4	40.90	16.23	42.87
1,500	.5	26.35	37.56	36.09
	7.5	40.91	15.76	43.32

Table 6

Particle Size Distributions of Wabamun Coal in Centrifuge Products: Solid Product

figures are percent of dry starting material

G →	775		1000							1505	
Feed Rate L/Min.	0.52	7.33	0.13	0.49	1.08	2.5	5.3	7.63	10.36	0.5	7.5
Retained on Tyler mesh											
14	0.38	0.18	0.72	0.60	0.44	0.84	0.77	0.52	0.99	0.33	0.76
20	7.68	9.91	8.58	8.03	7.37	10.56	9.40	6.70	10.03	6.27	8.51
28	20.65	19.74	30.02	23.31	21.03	22.65	20.33	17.57	19.42	21.81	19.33
35	19.31	16.97	31.67	22.10	19.32	18.85	18.10	16.61	16.76	24.23	15.89
48	15.21	15.19	17.46	15.22	16.66	16.35	14.48	15.49	14.46	17.58	15.91
65	9.66	10.46	6.32	9.03	10.65	10.01	10.0	11.30	11.07	10.34	11.31
80	3.64	4.46	1.05	3.04	3.67	3.43	3.76	4.10	4.26	3.31	4.22
100	2.87	3.43	0.73	2.59	2.96	2.70	3.33	3.40	3.54	2.55	3.49
150	4.09	5.36	0.78	3.41	4.18	3.80	4.60	5.02	5.31	3.43	5.14
200	3.74	3.90	0.59	2.68	3.35	2.92	3.75	4.08	4.09	2.40	4.16
325	2.80	3.53	0.44	2.15	2.56	2.21	2.88	3.36	3.29	1.63	3.48
-325	9.95	6.85	1.62	7.82	7.78	5.66	8.56	11.85	6.77	6.11	7.80
Sum	99.98	99.98	99.98	99.98	99.97	99.98	99.96	100.0	99.99	99.99	100.0

Table 7

Particle Size Distributions of Wabamun Coal in Centrifuge Products: Middlings (screen product)

Figures are Percent of Dry Starting Material

G	775		1000			1505	
Retained on Tyler Mesh \ Feed rate L/min.	0.52	7.33	0.13	0.49	7.63	0.5	7.5
14	0	0.13	0.09	0	0.07	0	0
20	0.14	0.13	0.06	0.03	0.12	0	0.05
28	0.14	0.12	0.34	1.85	0.20	0.43	0.14
35	0.99	0.63	2.97	1.77	1.12	1.61	1.30
48	7.84	6.47	14.90	10.51	7.37	11.40	8.41
65	14.27	11.86	19.00	15.35	14.36	16.15	13.90
80	7.38	7.15	8.39	7.76	7.44	7.90	7.09
100	6.31	6.19	6.63	6.68	6.27	6.47	6.52
150	11.35	12.07	10.23	10.97	11.33	10.71	11.07
200	9.64	10.51	8.13	8.38	9.42	8.57	9.18
325	11.19	14.78	6.92	8.71	10.86	8.20	12.29
-325	30.73	29.95	22.34	27.98	31.42	28.55	30.07
Sum	99.98	99.99	100	99.99	99.98	99.99	100.02

Table 8

Particle Size Distributions of Wabamun Coal in Centrifuge Products: Liquid Product

Figures are Percent of Dry Starting Material

G →	775		1000			1505	
Feed Rate L/Min.	0.52	7.33	0.13	0.49	7.6	0.5	7.5
Retained on Tyler Mesh	Effluent Colloidal						
28			1.0				0.7
35			0.25				2.1
48			2.0				6.1
65*			4.8				4.9
65	15.7	3.4	n. appl.	6.0	0.25	6.0	n. appl.
80	3.9	3.6	3.5	3.3	0.75	2.4	2.35
100	3.9	4.2	4.2	3.3	1.25	3.6	2.1
150	11.8	5.8	8.7	12.0	1.75	4.8	3.5
200	9.8	4.4	8.5	10.4	1.50	3.6	3.3
325	3.9	4.0	12.2	12.0	1.75	6.0	3.3
-325	51.0	74.7	55.2	53.0	92.7	73.5	71.5
Sum	100	100.1	100.35	100	99.95	99.9	99.85

* Without coarser sieves present

Table 9

Particle Size Distributions of Feed, Vesta Expt.

Analysis #	46	46 1/2	47	48	50	49	
Description	Dry Head Barrel #2, used in run	Dry Head, Barrel #1, not used in run	Wet Head, just after making slurry	End of Attrition Run after 4+ hrs. circulation	Feed to Centrifuge Upper Barrel (low feed rates)	Feed to Centrifuge Lower Barrel (high feed rates)	Birtley Wet Screening
% by weight retained on Tyler Mesh							
14	3.03	5.74	4.78	4.82	4.22	3.13	6.6
20	20.11	25.40	22.99	23.50	21.17	17.91	
28	20.44	21.66	20.94	20.95	20.30	20.0	38.0
35	14.95	13.92	13.48	13.44	13.63	13.75	
48	12.28	11.44	12.78	11.91	12.62	13.74	21.5
65	9.81	7.86	9.19	9.22	10.07	10.82	
80	4.43	3.36	3.82	3.76	4.03	4.37	
100	3.27	2.75	2.98	2.88	3.07	3.51	11.8
150	4.40	3.48	4.04	4.15	4.26	4.78	
200	2.74	2.07	2.61	2.61	2.52	3.02	5.6
325	1.30	1.24	1.56	1.63	1.51	1.94	1.6
-325	3.22	1.13	0.82	1.12	2.59	3.02	14.9
Percent by wt. Wet Solids in Coal Slurry	-	-	46.2	49.75	48.8	43.65	

Table 10

Bird Centrifugings on Vesta Coal Slurry, 45% Coal by wt. (nominal)

Coal, dry ρ = 1.482 g/mL, 21.21% H_2O w.b. Oil, ρ = 0.862 g/mL @ 21°C.

Slurry density 1.02 g/mL measured, 1.037 g/mL calculated

Average % Solids in Slurry 47.1 measured

Gravitational Accelerations	Feed Rate to Centrifuge, excluding wash of 105 ml/min (90 g/min)		Solid Product		Middlings		Liquid Product		Mass Balance per Minute		
	L/min	kg/min	Output, g/min	Wt % Coal	Output, g/min	Wt % coal	Output, g/min	Wt % coal	Income kg	Outgo kg	Relationship of outgo to income
775	0.53	0.54	197.5	93.4	191.4	35.9	224.4	0.49	0.61	0.61	Even
	7.7	7.85	3793.6	91.2	1007.2	30.5	3358.6	0.65	7.64	8.16	Over 6.8%
1000	0.11	0.112	25.3	94.3	97.3	n.d.	55.2	n.d.	0.20	0.178	Short 11%
	0.5 *	0.51	233.8	85.7	134.5	33.4	200.7	0.2	0.58	0.569	Short 2%
	1.01	1.03	448.2	91.0	287.2	n.d.	398.4	n.d.	1.08	1.134	Over 5%
	2.5	2.55	1062.3	91.1	530.9	n.d.	1140.7	n.d.	2.54	2.73	Over 7.5%
	3.6	3.67	1448.5	91.5	581.1	n.d.	1650.4	n.d.	3.62	3.16	Short 13%
	4.8	4.9	1694.7	90.3	742.9	n.d.	2368.3	n.d.	4.80	4.80	Even
	7.3 *	7.45	3270.9	90.8	1012.4	38.9	3303.1	1.3	7.25	7.59	Over 4.7%
	9.7	9.9	4735.3	90.85	1378.5	n.d.	4194.1	n.d.	9.59	10.31	Over 7.5%
1500	0.53	0.54	212.0	94.0	201.5	34.95	184.9	0.36	0.61	0.598	Short 2%
	7.7	7.85	3414.4	96.2	1004.6	37.1	3571.1	0.11	7.64	7.99	Over 4.6%

* Screen plugging observed

Table 11

Distribution of Centrifuge Products from Separation of Vesta Coal, per Minute

Gravitational Accelerations	Feed Rate, L/min	Solids, wt% of outflow	Middlings, wt% of outflow	Liquid, wt% of outflow
775	0.53	32.2	31.2	36.6
	7.7	46.5	12.3	41.2
1000	0.11	14.2	54.7	31.2
	0.5*	41.1	23.5	35.3
	1.01	39.5	25.3	35.1
	2.5	38.9	19.4	41.7
	3.7	39.4	15.8	44.85
	4.8	35.2	15.5	49.3
	7.3*	43.1	13.3	43.5
	9.7	45.9	13.4	40.7
1500	0.53	35.4	33.7	30.9
	7.7	42.7	12.6	44.7

*Screen plugging observed.

Table 12

Particle Size Distributions of Vesta Coal in Centrifuge

Products: Solid Product

figures are percent of dry starting material

G →	775		1000								1500	
Feed rate, L/min	0.53	7.7	0.11	0.5	1.01	2.5	3.7	4.8	7.3	9.7	0.53	7.7
Retained on Tyler Mesh												
14	4.73	3.75	1.59	3.19	3.78	4.55	4.07	2.99	4.06	4.11	3.66	3.49
20	26.06	22.33	13.01	16.26	28.92	25.88	23.38	19.77	22.05	21.65	23.41	21.14
28	29.23	22.17	32.25	23.58	30.37	26.11	23.93	21.56	23.25	21.34	30.12	22.31
35	18.72	14.84	32.45	18.38	17.74	17.42	16.40	15.45	15.41	14.28	20.10	15.19
48	11.52	12.71	14.07	13.67	10.17	11.82	12.87	13.90	12.28	12.52	10.22	12.78
65	3.99	9.63	3.70	8.43	4.09	6.70	7.97	10.01	9.04	8.95	4.35	8.35
80	1.14	3.39	0.82	2.72	1.10	1.88	2.82	3.84	3.40	3.70	1.31	3.28
100	0.77	2.73	0.54	2.15	0.76	1.38	2.09	3.02	2.66	3.01	1.02	2.64
150	0.96	3.62	0.53	2.75	0.98	1.94	2.69	3.96	3.38	4.08	1.35	3.51
200	0.71	2.29	0.20	2.08	0.75	0.77	1.63	2.23	1.99	2.80	0.67	0.87
325	0.48	1.52	0.16	1.64	0.43	1.04	0.90	1.88	0.99	2.03	1.19	3.72
Below 325	0.68	1.01	0.67	5.14	0.90	0.50	1.24	1.38	1.48	1.53	2.65	2.71

Table 13

Particle Size Distributions of Vesta Coal in Centrifuge

Products: Middling (Screen Product)

figures are percent of dry starting material

G	775		1000		1500	
Feed Rate, L/min	0.53	7.7	0.5	7.3	0.53	7.7
Retained on Tyler Sieve						
14	0	0.05	0.05	0.07	0	0
20	0.12	0.13	0.09	0.10	0.03	0.11
28	0.26	0.13	0.35	0.25	0.24	0.13
35	3.68	1.33	4.06	1.50	3.35	0.99
48	18.50	9.99	16.46	11.58	19.46	10.17
65	24.66	16.73	20.86	17.70	23.43	17.87
80	11.99	9.19	10.52	8.53	11.27	9.63
100	8.74	9.43	9.63	8.98	9.71	9.25
150	11.60	15.18	12.59	13.52	11.83	14.54
200	3.38	11.68	1.20*	10.07	6.86	11.01
325	8.08	9.99	13.06	9.39	4.64	10.37
Below 325	8.98	16.16	11.12	18.30	9.17	15.92

*Discovered hole in sieve

Table 14

Particle Size Distribution of Vesta Coal in Centrifuge Products: Liquid Product

figures are percent of dry starting material

G	775		1000		1500	
Feed Rate, L/min	0.53	7.7	0.5	7.3	0.53	7.7
Retained on Tyler Sieve						
14	-	-	-	-	-	-
20	-	-	-	-	-	-
28	-	-	-	-	-	-
35	-	-	-	-	-	-
48	-	-	-	-	-	-
65	5.19	5.17	24.32	6.60	47.91	12.07
80	2.60	0.86	2.70	0.94	6.25	4.31
100	1.30	0.86	2.70	0.94	6.25	3.45
150	3.89	0.86	2.70	0.94	2.08	7.76
200	7.79	1.73	5.41	1.89	6.25	6.89
325	9.09	0.86	5.41	2.83	4.17	4.31
Below 325	70.14	89.65	56.75	85.85	27.08	61.20

Table 15

Particle Size Distributions of Feed, McIntyre Expt.

Analysis #	89	90	91	92	93	94	95	Birtley
Description	Dry Head	Start of Attrition Run (wet head)	Attrition Run, 2 hr	Attrition Run, 5 hr	End of Attrition Run 6 1/2 hr	Slurry in Upper Barrel Low Feed Rates	Slurry in Lower Barrel High Feed Rates	Said to be wet screened
Retained on Tyler Mesh								
14	2.51	3.12	2.77	2.23	2.44	2.68	1.96	3.4
20	14.16	13.49	13.44	12.61	12.41	14.67	11.68	
28	15.88	13.97	14.34	14.10	14.07	15.30	13.56	23.2
35	11.82	10.79	11.05	10.87	10.64	10.65	10.80	
48	11.35	10.03	10.04	10.09	9.82	10.31	10.28	21.7
65	8.87	8.05	8.84	8.45	8.76	8.17	8.40	
80	3.99	4.23	4.53	3.96	4.05	3.85	4.25	
100	3.48	3.54	3.29	3.53	3.52	3.31	3.45	16.1
150	5.49	5.95	7.64	5.58	5.75	5.47	6.20	
200	4.56	5.78	6.94	5.48	5.54	5.27	5.80	11.7
325	5.32	5.88	4.75	5.44	5.76	5.13	5.85	5.3
-325	12.56	15.17	12.28	17.67	17.27	15.17	17.74	18.6
Percent by wt. wet solids in Oil Slurry	---	53.32	53.93	53.63	53.44	55.86	52.45	---

Table 16

Bird Centrifugings on McIntyre Coal Slurry, ~ 54% Coal by wt. (experimental value)

Coal, dry ρ = 1.367 g/mL; 2.66/1.50% H_2O; wet ρ = 1.354 g/mL.
Oil, ρ = 0.862 g/mL at 21°C
* H = high screen wash, 250 mL = 215.5 g per minute †R = full recycle of middlings to feed
Slurry density 1.05 - 1.09 mL measured; 1.071 g/mL calculated

Gravitations Accelerations	Feed Rate to Centrifuge. Screen wash normally 105 ml/min = 90 g/min		Solid Product		Middlings		Liquid Product		Mass Balance per Minute		
	L/min	kg/min	Output g/min	wt% Coal	Output g/min	wt% Coal	Output g/min	wt% Coal	Income, kg	Outgo kg	Relationship of Outgo to Income
775	0.52	0.557	219.45	92.25	135.6	56.1	169.9	0.87	0.647	0.525	Short 18.9%
	2.5	2.68	1113.8	91.0	686.4	n.d.	865.6	n.d.	2.77	2.67	Short 3.6%
	7.7	8.25	3899.2	89.7	1439.4	46.2	2690.4	4.76	8.34	8.03	Short 3.7%
1000	0.11	0.118	44.0	95.0	111.0	n.d.	34.6	n.d.	0.209	0.190	Short 9.1%
	0.51	0.546	304.05	93.3	240.2	50.0	161.2	0.68	0.636	0.705	Over 10.8%
	0.51H* ⓟ	0.546	258.1	93.2	363.0	31.3	164.0	0.82	0.762	0.785	Over 3%
	0.49R†	0.525	761.1	89.7	----	----	213.3	4.09	0.615	0.974	Over 58%
	0.49HR *†	0.525	343.6	n.d.	----	----	184.1	n.d.	0.740	0.528	Short 28.6%
	1.0	1.07	596.7	91.8	351.6	n.d.	332.0	n.d.	1.16	1.28	Over 10.3%
	2.4	2.57	1330.4	92.0	677.0	n.d.	790.0	n.d.	2.66	2.80	Over 5.3%
	5.5	5.89	2773.0	90.9	1066.9	n.d.	1989.7	n.d.	5.98	5.83	Short 2.5%
	7.59	8.13	3357.5	90.0	1417.4	49.5	2966.7	3.85	8.22	7.74	Short 5.8%
	7.59H*	8.13	3828.7	89.45	1497.8	46.2	2895.4	4.11	8.345	8.22	Short 1.5%
	7.59R †	8.13	3963.7	88.05	----	36.8	2947.5	4.36	8.22	6.91	Short 15.9%
	9.65	10.34	4592.5	90.1	1820.25	n.d.	3458.8	n.d.	10.43	9.87	Short 5.4%
1500	0.51 ⓟ	0.546	178.8	94.0	145.0	44.3	171.1	1.06	0.636	0.495	Short 22.2%
	7.45	7.98	3555.2	90.3	1473.0	53.4	2832.6	3.77	8.07	7.86	Short 2.6%

ⓟ Screen plugging observed

Table 17

Distribution of Centrifuge Products from Separation of McIntyre Coal

H= high screen wash R= middlings recycle

G	Feed Rate, L/min	% Solids	% Middlings	% Liquid
775	0.52	41.9	25.8	32.3
	2.5	41.8	25.75	32.45
	7.7	48.6	17.9	33.5
1000	0.11	23.2	58.5	18.25
	0.51	43.1	34.05	22.85
	0.51H*	32.9	46.2	20.9
	0.49R	78.1	----	21.9
	0.49HR	65.1	----	34.9
	1.0	46.6	27.5	25.9
	2.4	47.6	24.2	28.2
	5.5	47.6	18.3	34.1
	7.59	43.4	18.3	38.3
	7.59H	46.8	18.2	35.2
	7.59R	57.35	----	42.65
	9.65	46.5	18.4	35.0
1500	0.51*	36.1	29.1	34.6
	7.45	45.2	18.7	36.0

* Screen plugging took place.

Table 18

Particle Size Distributions of McIntyre Coal in Centrifuge Products: Solid Product

figures are percent of dry starting material

G	775			1000											1500	
Feed Rate, L/min	0.52	2.5	7.7	0.11	0.51	0.51 High Screen Wash	0.49 Full Recycle	1.0	2.4	5.5	7.59	7.59 High Screen Wash	7.59 Full Recycle	9.65	0.51	7.45
Retained on Tyler Mesh																
14	0.45	0.95	1.95	0.30	0.20	0.16	0.23	0.31	0.75	1.25	1.58	1.37	1.31	1.69	0.55	1.12
20	5.07	10.93	12.91	2.97	2.19	1.79	2.13	4.10	8.40	10.98	11.55	11.22	9.49	12.03	4.91	9.15
28	12.58	16.31	16.13	9.97	8.20	7.74	5.98	10.58	14.16	15.75	15.24	15.15	13.91	15.17	13.51	14.56
35	13.54	12.97	12.66	12.52	11.51	11.57	6.67	11.28	11.66	12.04	11.51	11.35	11.29	11.60	15.80	11.93
48	12.31	11.73	11.21	14.13	13.45	14.75	8.84	11.18	11.69	11.75	11.95	11.82	11.12	11.95	14.78	11.22
65	9.41	8.98	8.72	11.39	11.99	12.06	8.80	9.30	9.02	9.00	9.28	8.35	9.07	9.59	11.15	9.52
80	4.43	3.89	4.22	5.29	5.46	5.60	4.79	4.80	4.58	4.07	4.30	4.15	4.48	4.27	4.84	4.41
100	3.68	3.20	3.42	4.15	4.70	4.22	4.13	3.87	3.67	3.34	3.28	3.35	3.63	3.50	3.72	3.65
150	6.41	5.25	5.61	7.06	7.71	7.65	8.68	7.32	6.37	5.48	5.94	6.01	6.21	6.01	6.18	6.36
200	6.17	4.83	5.17	6.46	7.08	6.81	8.46	6.78	5.87	4.96	5.15	5.49	5.91	5.28	[illegible]	5.91
325	6.36	5.02	5.06	6.49	6.97	7.06	9.14	7.07	5.91	5.11	5.57	5.75	6.34	5.17	5.06	6.13
Below 325	19.59	15.93	12.93	19.26	20.53	20.58	32.15	23.40	17.89	16.26	14.65	15.98	17.24	13.73	14.29	16.04

Table 19

Particle Size Distributions of McIntyre Coal in Centrifuge Products: Middlings (Screen Product)

figures are percent of dry starting material

G	775		1000					1500	
Feed Rate, L/min	0.52	7.7	0.51	0.51 HIGH SCREEN WASH	0.49 MIDS BEING RECYCLED	7.59	7.59 HIGH SCREEN WASH	0.51	7.45
Retained on Tyler Mesh									
14	---	0.02	0.04	0.16	0.08	0.01	0.03	0.04	----
20	0.05	0.04	0.27	0.32	0.05	0.03	0.04	0.08	0.06
28	0.20	0.07	0.31	0.49	0.08	0.08	0.09	0.21	0.13
35	0.90	0.58	1.13	1.58	0.35	0.63	0.58	1.17	0.86
48	7.56	5.06	9.48	9.35	3.15	6.12	5.70	9.58	7.15
65	11.82	8.56	12.14	12.10	5.32	9.05	8.89	12.41	10.28
80	6.51	4.98	7.11	6.50	3.53	5.30	5.26	6.57	5.72
100	5.45	4.91	5.64	5.54	3.29	5.08	5.36	5.74	5.08
150	9.90	9.34	9.94	9.56	6.56	9.71	9.99	9.96	9.95
200	9.09	10.13	9.31	9.04	7.18	10.4	10.81	9.01	10.56
325	10.26	12.75	9.33	8.93	8.42	12.5	12.72	9.46	12.26
Below 325	38.25	43.55	35.29	36.52	61.99	41.22	40.53	35.77	37.94

Table 20

Particle Size Distributions of McIntyre Coal in Centrifuge Products: Liquid Product

figures are percent of dry starting material

G	775		1000						1500	
Feed Rate, L/min	0.52	7.7	0.51	0.51 High Screen Wash	0.49 Full Recycle	7.59	7.59 High Screen Wash	7.59 Recycle	0.51	7.45
Retained on Tyler Mesh 14	----	----	----	----	----	----	----	----	----	----
20	----	----	----	----	----	----	----	----	----	----
28	----	----	----	----	----	----	----	----	----	----
35	----	----	----	----	----	----	----	----	----	----
48	----	----	----	----	----	----	----	----	----	----
65	9.17	8.45	8.27*	6.59	0.31	0.66	1.24*	0.41	24.0	1.17
80	5.80	1.55	0.75	0.60	0.92	0.13	0.83	0.28	4.44	0.23
100	7.24	0.68	0.75	2.99	0.76	0.2	0.83	0.41	4.0	0.12
150	10.63	2.62	3.0	1.80	0.76	0.13	1.65	1.10	6.22	0.12
200	9.18	1.75	3.0	1.20	5.05	0.26	1.24	0.69	6.22	0.47
325	8.69	1.46	1.50	0.60	6.42	0.13	1.10,	0.55	6.22	0.23
Below 325	49.28	83.77	82.72	86.23	85.78	98.43	93.11	96.55	48.89	97.66

* Weight inflated by paper residue from filter.

Table 21

Initial Solids Content and Particle Size Distributions, Task 4 Slurries

Coal	Wabamun		Vesta		McIntyre			
Analysis #	162	161	172	173	145	146	147	148
Circumstances	Low Feed Rate (Upper Barrel)	High Feed Rate (Lower Feed Barrel)	Wet Head After Mixing Before Attrition	End of Attrition	Start of Attrition	Attrition Run at Half Time	End of Attrition	End of Attrition after adding 60L old slurry
Wt. % Coal	49.32	50.24	46.02	47.09	51.02	51.57	52.35	53.50
% by weight retained on Tyler Sieve								
14	1.31	1.19	3.97	4.01	2.93	2.91	2.84	3.22
20	9.88	9.32	21.34	21.23	13.99	14.00	14.41	14.59
28	17.71	17.56	19.66	20.02	15.11	15.01	15.21	15.60
35	15.10	14.34	13.75	12.93	10.95	10.68	11.23	11.45
48	13.81	14.58	11.77	12.11	11.33	11.05	10.21	10.28
65	11.27	11.55	8.99	9.22	9.00	8.50	8.67	8.69
80	4.75	4.77	4.01	3.94	4.30	4.14	4.01	4.44
100	3.89	4.02	3.28	3.16	3.78	3.59	3.27	3.23
150	5.81	6.30	4.47	4.28	6.20	5.62	5.56	6.55
200	5.26	5.51	3.31	3.34	5.90	5.47	5.31	6.00
325	4.82	5.25	1.98	2.07	7.75	5.23	5.10	6.00
-325	6.42	5.61	3.44	3.69	8.75	13.80	14.18	9.94

Table 22

Task 4 Centrifugings on Coal Slurries
All at 1000 G

Screen Wash 250 mL/min of 0.862 g/mL liquid product unless otherwise noted

*Screen wash 50 mL/min +Screen wash 100 mL/min

Coal % Solids, Slurry Density	Feed Rate to centrifuge		Solid Product		Middlings		Liquid Product		Mass Balance per Minute		
	L/min	kg/min	Output, g/min	wt % Coal	Output, g/min	wt % Coal	Output, g/min	wt % Coal	Income, kg	Outgo, kg	Relationship of outgo to income
Wabamun 50.24% solids, ρ = 1.047 g/mL	0.5	0.52	198.82	94.28	256.58	30.05	187.05	0.94	0.56*	0.64	Over 14.3%
	4.0	4.2	1616.61	98.50	998.08	40.78	1642.96	2.03	4.42	4.26	Short 3.6%
	7.65	8.0	3439.72	91.71	1482.54	40.55	3120.23	2.80	8.21	8.04	Short 2%
Vesta 47.1% solids, ρ = 1.02 g/mL	0.5	0.51	194.06	97.23	116.93	42.68	201.96	0.60	0.55*	0.51	Short 7%
	1.0	1.02	479.58	97.85	281.46	23.61	406.85	0.33	1.106+	1.168	Over 5.6%
	4.0	4.08	1770.96	90.82	842.52	29.56	2407.68	9.8	4.29	5.02	Over 17%
	7.5	7.65	3275.48	94.32	964.92	29.37	3256.85	0.57	7.87	7.50	Short 4.7%
McIntyre 53.5% solids, ρ = 1.02 g/mL	0.5	0.51	217.49	94.40	204.74	46.20	167.05	0.85	0.55*	0.59	Over 7.2%
	1.0	1.02	493.77	95.02	356.12	59.49	338.91	0.82	1.106+	1.189	Over 7.5%
	4.0	4.08	1491.64	95.69	998.62	47.35	1630.56	3.58	4.29	4.12	Short 4%
	7.5	7.65	3619.2	90.06	1288.17	47.93	2948.4	3.79	7.87	7.856	Short 0.2%

Table 23

Proportions of Products in Task 4 Centrifugings

Coal Slurry	Feed Rate, L/min.	% as Solids	% as Middlings	% as Liquid
Wabamun	0.5	30.95	39.94	29.11
	4.0	37.97	23.44	38.59
	7.65	42.72	18.41	38.87
Vesta	0.5	37.83	22.80	39.37
	1.0	41.05	24.11	34.84
	4.0	35.27	16.78	47.95
	7.5	43.69	12.87	43.44
McIntyre	0.5	36.91	34.74	28.35
	1.0	41.54	29.95	28.51
	4.0	36.20	24.23	39.57
	7.5	46.07	16.40	37.53

Table 24

Particle Size Distribution of Solids in Solid Products from Task 4 Centrifugings

Coal	WABAMUN			VESTA				MCINTYRE			
Feed Rate L/min	0.5	4.0	7.65	0.5	1.0	4.0	7.5	0.5	1	4	7.5
P.S.D. of Solids Tyler Mesh, % Retained											
14	0.38	0.62	0.08	3.75	2.86	2.77	3.71	0.08	0.33	1.03	1.44
20	6.43	7.30	9.79	24.62	19.22	21.78	22.84	1.56	4.87	9.52	10.74
28	21.35	18.68	19.31	27.53	21.71	22.94	21.89	6.00	12.59	15.61	14.69
35	21.80	18.35	16.14	18.45	16.43	15.25	13.89	8.70	14.56	12.68	11.06
48	16.57	15.24	15.16	10.58	13.44	13.44	11.56	13.47	15.34	12.48	11.29
65	9.85	10.44	10.32	6.04	9.83	8.74	7.56	12.74	12.45	9.28	8.48
80	3.83	3.98	4.44	2.10	3.79	3.86	3.46	5.87	5.19	4.75	4.01
100	2.75	2.89	3.40	1.36	2.81	2.66	2.48	4.63	4.03	3.59	3.37
150	4.79	4.51	5.12	1.64	3.72	3.59	3.84	8.46	6.27	5.85	5.38
200	3.98	3.44	4.23	0.97	2.36	2.48	2.69	7.43	5.41	5.27	5.33
325	3.71	2.69	3.38	0.58	1.45	1.72	1.51	7.75	4.82	5.02	5.24
Minus 325	4.50	11.86	8.68	2.38	2.36	0.77	4.57	23.21	14.13	14.90	18.96

Table 25

Particle Size Distributions of Solids in Middlings from Task 4 Centrifugings

Coal	WABAMUN			VESTA				MCINTYRE			
Feed Rate L/min	0.5	4.0	7.65	0.5	1.0	4.0	7.5	0.5	1.0	4.0	7.5
% Retained on Tyler Mesh											
14	0	0.02	0.03	0.03	0.08	0	0.02	0.17	0.09	0	0.02
20	0.14	0.02	0.03	0.14	0.42	0.06	0.02	0.04	0.41	0.19	0.36
28	0.27	0.06	0.03	0.36	0.66	0.06	0.04	0.08	0.57	0.45	0.44
35	1.56	0.80	0.59	1.46	1.00	0.72	0.82	0.87	0.80	0.99	0.95
48	10.48	6.30	5.31	12.26	7.49	8.81	7.74	6.32	2.96	5.72	6.42
65	16.03	10.92	8.40	21.61	15.72	17.57	14.00	10.71	8.87	9.31	9.66
80	8.46	6.64	6.04	12.29	8.97	10.82	9.25	6.33	6.51	5.41	5.75
100	7.16	5.88	5.29	8.63	7.86	9.01	7.85	5.58	6.62	5.18	5.40
150	10.92	10.71	10.28	13.64	12.25	14.75	14.38	9.77	11.07	9.78	10.05
200	9.89	10.13	11.03	9.97	10.91	12.98	12.57	9.89	10.92	10.55	10.73
325	9.29	10.18	11.61	6.60	8.92	10.29	11.15	10.03	15.21	11.47	11.75
Minus 325	25.80	38.34	41.36	13.00	25.71	14.93	22.16	40.20	36.96	40.94	38.45

Table 26

Particle Size Distributions of Solids in Liquid Products from Task 4 Centrifugings

Coal	WABAMUN			VESTA				MCINTYRE			
Feed Rate L/min	0.5	4.0	7.65	0.5	1.0	4.0	7.5	0.5	1	4	7.5
Retained on Tyler Mesh								Effluent Colloidal	Effluent Colloidal		
+65	2.22	2.22	0.43	6.89	10.0	24.66	8.64	5.62	7.97	6.69	1.04
80	0.74	0.94	0.43	1.15	3.33	9.45	1.23	3.93	3.62	2.75	0.69
100	0.74	0.32	0.43	2.30	3.33	8.20	1.23	6.18	2.90	2.75	0.87
150	1.48	0.32	0.22	5.75	6.67	14.02	1.23	13.48	5.80	4.60	1.74
200	3.74	0.32	1.95	3.45	11.67	12.66	1.23	11.80	2.17	4.33	0.52
325	5.19	0.63	0.22	4.60	11.67	10.22	2.47	9.0	4.35	4.20	0.69
-325	85.90	95.25	96.32	75.86	53.33	20.78	83.97	49.99	73.19	74.68	94.46
ALL FIGURES PERCENT RETAINED											

Table 27

Moisture Determination by Drying with P_2O_5

Sample	Wt coal or oily product g	Wt dry P_2O_5 g	Wt damp P_2O_5 g	H_2O Absorbed less 0.14 g in Air in Vessel g	Found Moisture w.b. %	Expected Moisture w.b. %
Wabamun Dry Head	48.77	33.10	41.95	8.71	17.86	17.25 Table 2
Vesta 7.3 L/min 1000G, Solid Product.	27.19	18.97	24.43	5.32	19.57	Tables 2 and 10: 21.21 x 0.9076 = 19.25
Vesta 7.3 L/min 1000G, Liquid Product	121.24	10.12	10.44	0.18	0.15	Tables 2 and 10: 13.7 x 0.013 = 0.27

DSS File No. 17SQ.23440-0-9073

APPENDIX "A"

TITLE: COAL-OIL SLURRY SEPARATION BY CONTINUOUS SCREEN BOWL CENTRIFUGE

REQUIREMENT

The requirement is for experimental examination of centrifugal separation of coal and oil from simulated long distance pipeline slurries.

1. Investigation of conditions of slurry separation in a continuous screen bowl centrifuge to produce low solid contents in separated crude oils and simultaneously low oil contents in coal cakes.
2. Evaluation of the properties of separated crude oils as feeds for oil refineries.

CONSTRAINTS

A clean metallurgical coal and thermal coal, all ground to pipelines specifications (-14 mesh with 15% - 375 mesh (sic)*) shall be mixed with synthetic crude oil. All used materials are specified in Task 1. The slurry of metallurgical coal shall be of 50% wt solids and slurries of thermal coals of 45% wt. The amount of each slurry sample required for all tests is estimated to be 500 kg.

Each slurry shall be circulated in a suitable pipeline test facility for simulation of a 3000 km pipeline transport.

A 6" Bird Machine Company continuous screen bowl centrifuge shall be used for separation tests. Slurry feed rate range shall be restricted to 0.1 and 10 kg/min. The centrifuge may be rented from Bird Machine Company. Approximate specifications for the centrifuge are listed in Table 1.

STATEMENT OF WORK

Task 1. Preparation of three (3) coal/oil slurries; two (2) with a

* -375 mesh in original. Should have been "-325 mesh".

thermal coal and one (1) with a metallurgical coal. The contractor will be responsible for collection, transportation of coal, oil, slurries, cakes, effluents and as well as preparation of all slurry samples. The following coal and oil samples shall be used (subject to approval by the mining company):

Coal Sample No. 1 - a subbituminous C coal, preferably from Morinville/Tofield/Battle River, Alberta coal area with max. moisture content of 30% wt and max. ash content of 12% wt.

Coal Sample No. 2 - a subbituminous B coal, preferably from Wabamun (Sundance)/Wetaskiwin, Alberta coal area, with max. moisture content of 20% wt and max. ash content of 15% wt.

Coal Sample No. 3 - a metallurgical coal preferably from Smoky River coal area, with max. moisture content of 7% and max. ash content of 9%.

N.B. All coal samples should be freshly mined and prepared by standard coal preparation operation.

Oil Sample - a regular synthetic crude oil sample obtained from Syncrude Ltd., directly from Fort McMurray plant. Before commencement of centrifugal tests, the contractor will deliver to CANMET, in air-tight containers, the following set of original samples:

5 kg of each subbituminous coal, 50 kg of metallurgical coal, 5 litres of synthetic crude oil and a 50 kg sample of metallurgical coal ground to pipeline specifications.

Task 2. Conducting a series of separation tests on the centrifuge at a centrifugal force of 1000 G with feed rate as a major variable within range from 0.1 to 10 kg/min. Also conducting tests at a centrifugal force of 1500 G and 750 G at a feed rate of 0.5 and 5 kg/min. Tests with mixtures

of feed and screen products for evaluation of the effects of screen product recirculation properties of effluent and cake will also be required.

Task 3. Determination of solid and water contents of all in and out centrifuge streams from Task 2 and particle size distribution in effluents down to 0.3 μm. Analysis techniques to be agreed with the Scientific Authority; if necessary these analyses can be subcontracted.

N.B. The centrifuge effluents sub micron analysis for particle size distribution can be done by the Western Research Laboratories of CANMET, c/o Alberta Research Council, Edmonton, Alberta. Contact Dr. Hamza.

Task 4. Based on the results from Tasks 2 and 3 above, the remaining slurries will be centrifuged at conditions selected by the Scientific Authority. Samples of each effluent will be prepared for evaluation of oil quality as a refinery feedstock (proposed analyses are listed in Table 2). The contractor will arrange for one (1) independent oil refiner to make these evaluations; appropriate samples of effluents will be provided by the Contractor, with a similar sample being sent to CANMET. The refiner must also receive a sample (2 litres) of the crude oil used to make the slurries. It is expected that between 3 and 5 separate centrifuge runs will be made for each slurry, resulting in 9 to 15 samples to be evaluated by the refiner, and by CANMET. The samples should each be of 20 litres. The Contractor will also perform the analyses of Task 3 to these samples. After completion of separation tests, the contractor will send remaining effluent samples to the Scientific Authority.

Task 5. For each centrifuge run described in Task 4, the Contractor will prepare a sample of coal cake, of at least 45 kilograms, to be stored in the absence of air. These samples will be held by the Contractor until

disposal instructions are given by the Scientific Authority (this will be done before the end of the contract; it is intended that these samples will be used as feed for further tests). The cake stream analyses of Task 3 will also be carried out for each cake sample.

Table 1. Continuous Screen Bowl Centrifuge
(Bird Machinery Company)

	Suggested Specifications
Pool bowl diameter	150 mm
Screen bowl diameter	125 mm
Total length	305 mm
Pool length	168 mm
Screen openings	0.2 mm
Minimal pool depth	1.6 mm
Scroll pitch	25.0 mm
Maximum bowl speed	4000 rpm
Middle bowl speed	3500 rpm
Minimum bowl speed	3000 rpm
Bowl/scroll gear ratio (if fixed)	100:1

Table 2. Analyses of Crude Oils and Effluents

Item	Suggested Method or Standard	Range	Comments
Analyses of samples "as received"			
Density		34-40 API	
B.S. & W sedimentation	ASTM D 1796	0.1 - 10%	
Sulphur	ASTM D 1552	0.2 - 1%	
Conradson carbon residue	ASTM D 189	0.5 - 12%	
Nitrogen	Kjeldahl Microcoulometer	0.1-0.25%	
Distillation, distillate and bottom analyses			
Engler distillation	ASTM D-86	initial /343°C	
Chloride in distillate	Microcoulometer	1 - 5 ppm	
Ash in bottom		0.05 - 3%	
Fe, Ni and V in ash			
Analyses of Superclassified filtrate*			
Sulphur	as per No. 4		
Conradson carbon residue	as per No. 5		
Analyses of sediment (from B.S. & W or superclarification)			
Sulphur	as per No. 4		
Conradson carbon residues	as per No. 5		

* Filtration through filter paper of specified pores less than 10 μm or additional centrifugal separation at extreme conditions (to remove of $D_p > 0.1$ μm)

APPENDIX B

IMPERIAL OIL ANALYSES ON LIQUIDS

SAMPLE NUMBER	SAMPLE IDENTIFICATION
1	Vesta, 1 L/min, Liq. Prod.
2	McIntyre, 7.5 L/min, Liq.
3	McIntyre, 4 L/min, Liq. Prod.
4	McIntyre, 0.5 L/min, Liq. Prod.
5	McIntyre, 1 L/min, Liq. Prod.
6	Vesta Coal, 4 L/min, Liq.
7	Wabamun, 4 L/min, Liq.
8	Vesta, 7.5 L/min, Liq.
9	Wabamun, 7.5 L/min, Liq.
10	Vesta, 0.5 L/min, Liq.
11	Wabamun, 0.5 L/min, Liq.
12	E725-16 coal/oil, oil as received

Imperial Oil Liquid Product Analyses

SAMPLE #	1	2	3	4	5	6	7	8	9	10	11	12
TEST												
DEN. g/L	892.7	894.2	896.6	889.1	897.6	889.6	903.8	889.5	898	891.5	898.8	871.3
BS&W. VOL %	1.1	6.0	5.6	2.2	3.0	2.5	2.8	2.4	4.2	1.0	1.2	.05
SULPHUR WT %	.19	.20	.19	.22	.19	.19	.18	.19	.18	.19	.19	.14
N_2 ppm	9.1	4.6	3.1	3.1	7.9	4.3	5.2	2.3	7.1	6.4	14.9	15.2
IBP, °F	260	226	221	253	352	236	339	217	305	241	380	101
5	314	282	292	312	365	290	379	286	381	317	363	162
10	366	354	350	364	382	345	407	397	411	378	395	253
20	442	430	427	435	428	424	461	419	463	439	447	383
30	488	484	485	490	490	481	507	476	510	492	497	467
40	534	534	539	542	537	532	558	530	559	542	544	520
50	576	576	584	585	576	580	600	579	605	587	589	571
60	620	624	628	630	619	625	635	623	645	631	633	620
70	666	670	670	682	667	668	Cracked	668	687	675	674	676
80	716	Cracked	Cracked	723	710	713	@ 662 °F	711	700	715	712	719
90	Cracked	@ 720 °F	@ 702 °F	Cracked	724	728	70% Rec	Cracked	Cracked	726 °F	722 °F	737 °F
95	@ 750 °F	81.0%	81.0%	@ 747 °F	Cracked	Cracked		@ 719 °F	@ 725 °F	Cracked	Cracked	Cracked
FBP	86% Rec	Rec	Rec	92% Rec	@ 726 °F	@ 728 °F		90% Rec	90% Rec	@ 726	@ 722	@ 737
					91% Rec	92% Rec				90% Rec	90% Rec	90% Rec
Cl^- ppm (on Dist. Ov'Hd)	1.4	0.9	0.7	0.7	0.8	1.4	0.5	0.8	1.1	0.9	1.0	0.8
M.C.R. wt% (whole sample)	0.52	3.26	2.61	1.42	1.61	0.66	1.54	0.79	2.06	0.46	0.62	0.05

Rec. = Recovery

(cont'd)

Imperial Oil Liquid Product Analyses (cont'd)

	1	2	3	4	5	6	7	8	9	10	11	12
Ash Wt. % (on Dist Btms.)	.84	.91	1.18	.64	.72	2.94	1.67	2.49	5.9	1.52		.01

Analysis of Centrifuged Material

Liquid

Sulphur wt.%	0.21	0.20	0.19	0.20	0.20	0.20	0.21	0.20	0.20	0.21	0.21	0.20
MCR wt.%	0.07	0.06	.03	.03	0.05	.03	.03	.04	0.04	0.04		.03

Sediment

Sulphur wt.%	0.21	0.29	0.37	0.38	0.24	0.34	0.21	0.24	0.19	0.26	0.18	No Sediment
MCR wt.%	19.5	44.8	42.4	42.4	13.6	30.5	25.5	24.5	14.5	23.9	13.6	

(cont'd)

IMPERIAL OIL LIQUID PRODUCT ANALYSES, (continued)

METAL ANALYSIS OF ASH BY EMISSION SPECTROSCOPY

Sample	Major, >10 wt%	Minor, 1-10 wt%	Trace, <1 wt%
1	Aluminum Iron Barium Magnesium	Zinc	Copper Boron
2	Aluminum Iron	Zinc Barium Magnesium	Copper Boron
3	Aluminum Iron	Zinc Barium Magnesium	Copper Boron
4	Aluminum Iron Barium	Zinc Magnesium	Copper Boron
5	Aluminum Iron Magnesium	Zinc	Copper Boron
6	Aluminum Iron Barium Magnesium	Zinc	Copper Boron

(cont'd)

Imperial Oil Liquid Product Analyses (concluded)

Sample	Major, 10 Wt% or more	Minor, 1-10 Wt%	Trace, < 1 %
7	Aluminum	Zinc	Copper
	Iron		Boron
	Magnesium		
8	Aluminum	Barium	Copper
	Iron	Zinc	Barium
	Magnesium		Sodium
9	Aluminum	Zinc	Copper
	Iron	Barium	Boron
	Magnesium	Sodium	
10	Aluminum		Copper
	Iron		
	Silicon		
	Calcium		
11	Not		
	Sufficient Ash		
12	No Ash		

APPENDIX C

Data on Duro twin-piston pump, Model E720

Serial #7-8102

Motor: 1725 r.p.m. 1/2 H.P.

Motor pulley Ø: 2" (5.08 cm)

Pump pulley Ø: 12" (30.48 cm)

Strokes/min: $1725 \times \frac{2}{12} = 287.5$

Stroke: 1 1/2" (3.81 cm)

Cylinders: 2, both double-acting, 1 5/8" (4.1275 cm) in diameter.

Volume swept out by piston per min:

$$3.81 \times \pi \left(\frac{4.1275}{2}\right) \times 2 \times 2 \times 287.5 = 58{,}625 \frac{cm^3}{min} = 58.6 \frac{L}{Min}$$

Observed pumping rate 50.9 ^{L}/min on water.

Valve clearances: 3 mm

Max. pressure developed: 65 p.s.i.

Made by Pumps and Softeners Limited

680 Waterloo Street

London, Ontario